

## **APPENDIX B**

### **EXISTING REACH CONDITIONS AND DATA SUMMARY**

#### **B.1 INTRODUCTION**

The State of Montana Department of Justice Natural Resources Damage Program (NRDP) retained WestWater Consultants, Inc. (WWC) to conduct a detailed existing conditions assessment of the Clark Fork River (CFR) and Blackfoot River (BFR) in the vicinity of Milltown Dam near Bonner, Montana. The primary goal of the project was to refine and validate the Draft Conceptual Restoration Plan for the Clark Fork River and Blackfoot River near Milltown Dam (DCRP) prepared in 2003 by Water Consulting, Inc. and Wildland Hydrology. The DCRP developed a coarse level approach to restoration of the Clark Fork and Blackfoot rivers based on limited field data and information. To supplement existing information and provide a robust data set from which to finalize a restoration plan for river reaches associated with the Milltown Reservoir Sediments Operable Unit (MRSOU), a Sampling and Analysis Plan (SAP) was developed by NRDP and WWC. The SAP was implemented in 2004-2005 by WWC and River Design Group, Inc. (RDG). This report presents and summarizes the methods and results of the data collection and analysis effort.

The NRDP in consultation with trustees and WWC identified the following objectives to be achieved with implementation of the SAP. The objectives included:

1. Conducting detailed reach assessments on the main stem Clark Fork and Blackfoot rivers to characterize existing and potential river and floodplain conditions;
2. Completing an aerial photo temporal geomorphic trend analysis on the main stem Clark Fork River from Turah Bridge downstream to Milltown Dam;
3. Evaluating the influence of valley morphology on channel form and process using a study reach on the Blackfoot River near Ovando, Montana; and
4. Compiling the data methods and results into a comprehensive report to serve as a support document for river and floodplain restoration design for stream reaches associated with the MRSOU.

This report is organized in five main sections. Section 1 provides a general project background and lists the primary objectives developed by NRDP and WWC. Section 2 details the data collection methodologies and techniques employed in the SAP. Sections 3 and 4 present the data and reach assessments followed by a compilation of the reference reach data developed for the Blackfoot and Clark Fork rivers in Section 5.

#### **B.2 SAMPLING AND ANALYSIS PLAN**

This section summarizes the field sampling methods and analysis techniques. Section B.2.1 provides a general description of the reaches and their geographic locations. Section B.2.2

describes the field sampling methodologies. Lastly, Section B.2.3 describes the data processing, analysis, and reporting methods.

## **B.2.1 Study Reaches**

### **B.2.1.1 Clark Fork River**

Channel reach assessments were completed on the Clark Fork River from Turah Bridge near Bonner, MT downstream to the Duck Bridge located approximately one mile upstream of Milltown Dam, and from Milltown Dam downstream to the USGS streamflow gaging station in East Missoula. This section of the Clark Fork River (CFR) from Turah Bridge downstream to Duck Bridge, referred to as CFR3 and the CFR upstream study reach (Figure 1-1) in this report, was delineated into the three sub-reaches based on existing channel conditions. Sub-reaches CFR3-A, CFR3-B and CFR3-C are delineated on Sheet I-7 in Appendix I.

Two additional CFR reaches, CFR2 and CFR1, were delineated. CFR2 occurred downstream of Duck Bridge to the confluence with the BFR. CFR2 existing conditions were not evaluated in this study. CFR 1 extended from the confluence with the BFR downstream to the Interstate 90 (I-90) bridges downstream from Milltown Dam. The lower CFR study reach included the reach from the I-90 bridges downstream to the U.S. Geological Survey (USGS) streamflow gaging station in East Missoula, and included Bandmann Flats. The Bandmann Flats section of the Clark Fork River was assessed to characterize potential reference conditions of the Clark Fork River downstream of Milltown Dam.

### **B.2.1.2 Blackfoot River**

Channel reach assessments were completed on the Blackfoot River at the USGS streamflow gaging station located near Bonner and at three additional sites in the upper watershed near the town of Ovando. Assessments near Ovando encompassed three reference reaches and included encompassed 2.6 miles of the Blackfoot River. The second study site was located 6.4 miles northeast of Bonner at the USGS streamflow gaging station, in the vicinity of the Angevine fishing access. The assessment included 2,900 ft of the Blackfoot River. Figures B.2-1 notes the reach location of the Blackfoot River at the USGS gaging station. Figure B-2 provides a general vicinity map of the assessment area near Ovando.

## **B.2.2 Data Collection Methods**

### **B.2.2.1 Channel and Floodplain Survey**

The reaches were surveyed with a Trimble 3303DR Total Station under the responsible charge of a professional land surveyor licensed to practice in the State of Montana. Photogrammetry was used to complement the Clark Fork River surveys and was performed on the greater floodplain and off channel areas within CFR 1, CFR 2, and CFR 3. Prior to field surveys, approximately 80 control points were established from Turah Bridge downstream to Milltown Dam using static Global Positioning System (GPS) observation. Static observations were performed with a Leica survey grade GPS unit. This step calibrated all control points to satellite GPS coordinates for

elevation definition. Field surveys were completed using a four to six person survey and hydrology crew.

### **B.2.2.2 Level I Characterization**

Prior to field survey, a Level I coarse screen analysis was completed to stratify the assessment areas into discrete channel reaches based on several criteria including: 1) dominant landform and valley type; 2) existing and predicted channel state and condition class; 3) existing and potential riparian community habitat types; and 4) the upstream extents of the direct and indirect effects of Milltown Dam. Table B-1 summarizes the general parameters used for initial stratification.

<b>Table B-1.</b> List of Level I coarse screen analysis parameters and methods.	
Parameter	Methods
Dominant landform and valley type	Rosgen, 1996
Existing channel state and condition class	Montgomery and Buffington, 1993 Rosgen, 1996
Potential channel state and condition class	Rosgen, 1996

### **B.2.2.3 Level II and III Existing Conditions and Departure Analysis**

Level II and III surveys were completed to characterize existing channel conditions and degree of stability. Aerial photos from 1937, 1956, 1966, 2000, 2003 and 2004 were georeferenced and mosaiced to evaluate channel pattern changes over time as well as land use development potentially impacting the form and function of the Clark Fork River.

Existing channel conditions were evaluated in terms of equilibrium state, or degree of stability. A stable river reach was defined as one in which the average channel dimensions remain more or less constant over time amidst ongoing bed and bank erosion and deposition, meander cutoffs, and lateral migration (Millar, 2005). The following objectives were developed for the Level I and III analyses (Rosgen, 1996):

1. Develop a quantitative basis for comparing reaches displaying similar morphologies, but which are in different conditions or geomorphic states;
2. Describe the river's potential condition, as contrasted with the existing condition;
3. Determine the departure of the river's existing condition relative to a reference baseline condition;
4. Measure field parameters that influence river state including flow regime, river size, sediment particle size distribution, sediment supply, channel stability, bank erodibility, and direct channel disturbances; and
5. Develop a basis for efficient validation sampling to be completed under subsequent phases of this project.

Table B-2 summarizes the data collection parameters.

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**Table B-2.** Summary of level II and III data collection parameters and methods.

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Cross-sections (Harrelson et al., 1994)  
Longitudinal profiles (Harrelson et al., 1994)  
Planform Geometry (Langbein and Leopold, 1966; Thorne, 1997)  
Substrate characterization (Wolman, 1954)  
Riffle Stability Index (Kappeser, 1993)  
Surface and subsurface particle distributions (Bunte and Abt, 2001)  
Bank Erodibility Hazard Index (D. Rosgen, 2001).

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#### Channel cross-sections

Representative channel cross-sections were surveyed using standard methods (Harrelson et al., 1994). Cross-sections spanned the active bankfull channel, adjacent floodplain, and low terrace features. Channel units were divided into habitat and channel unit types including pool, riffle, run, and glide features (Bisson et al., 1982). Cross-section distances and measurement frequency varied according to valley bottom and channel width, channel irregularity, and survey objective. Elevation changes (inflection points) in the channel and floodplain were detailed. Surveys detailed morphological features including terraces, floodplains, bankfull indicators, channel bed, channel thalweg, and water surface.

#### Longitudinal bed profiles

Longitudinal profiles were established in each surveyed reach and included a minimum channel distance equal to 20 times the average bankfull riffle width or two meander wavelengths. The profiles included consistent measurement of left and right channel bankfull indicators, channel thalweg, and water surface elevations at select locations along the profile typically at delineated channel habitat units (e.g. riffles). For stream reaches characterized by multiple active channels, the channel conveying the greatest percentage of the discharge at the time of the survey (near or at baseflow) was selected. Aerial photos were also used to determine the dominant active channel thread during bankfull discharge.

#### Planform geometry

Planform geometry, including radius of curvature, meander wavelength, channel belt width, and bankfull width were measured using aerial photography complemented by field survey methods described in Section B.2.1.1 (Langbein and Leopold, 1966; Thorne, 1997). Results were reported for actual distances as well as dimensionless ratios.

#### Substrate characterization

Channel materials were sampled in the project area to characterize existing bed material characteristics as well as to complement hydraulic and sediment transport modeling. Several sampling methods were employed to meet the requirements of these three goals.

The Wolman method (Wolman, 1954) was used to characterize the particle size distribution of channel materials. The material sampling locations were modified to ensure various habitat units were sampled proportionally according to their percent representation in the reach. The

intermediate axes of the particles were measured (Wolman, 1954; Bunte and Abt, 2001). Samples from habitat units were recorded separately and reported individually and as a composite.

We applied the Riffle Stability Index (RSI) to evaluate the particle size percentile of the riffle that is mobile (Kappesser, 1993). This method involved locating a riffle in relatively straight sections of the reach that displayed uniform depth in the cross-section. Particle size distribution on each riffle was determined by the Wolman (1954) method. Sampling points were identified by establishing a sampling grid, with transects extending across the bankfull width over the entire length of the sampled riffle. The intermediate axis of each particle was measured and tallied by size class (Kappesser, 1993). The cumulative percent finer was then plotted against the upper value for each size class to generate a cumulative particle size distribution curve (Kappesser, 1993).

A lateral bar or similar depositional feature was identified in close proximity to the sampled riffle. The intermediate axes of the 30 largest recently deposited particles were measured and the geometric mean calculated and compared with the cumulative particle size distribution of the riffle. The percentile of the cumulative particle size distribution corresponding to the geometric mean of the largest particle sizes on the lateral bar was recorded as the RSI value.

#### Surface and subsurface particle size distributions

Volumetric sampling was completed to characterize the channel armor layer and subsurface materials (Bunte and Abt, 2001). Two five gallon vinyl buckets (similar to the CSU barrel sampler presented in Bunte and Abt, 2001) with their bottoms removed were nested within each other. Samples were generally collected half way between the thalweg and the bankfull channel margin. The nested buckets were swiveled into the channel bed to get below the surface armor layer. Armor layer particles were removed from inside of the bucket and placed in a holding bucket. Particles that were intercepted by the nested buckets and had more than half of the particle protruding into the bucket were removed from the bed and also placed in the holding bucket. Particle texture, color, and size were used to differentiate between surface and subsurface particles. Once the bed armor material was removed, subsurface material was removed to a depth equal to twice the intermediate diameter of the largest particle in the surface armor. This depth was suggested by Rosgen (unpublished data) as a sufficient depth to characterize the subsurface particle distribution. Subsurface sediment was placed in a second holding bucket and kept apart from the surface materials.

Volumetric samples were wet sieved in the field using standard sieves and a field scale. Sieves were stacked according to sieve opening size with coarser sieves on top and the finest sieve on the bottom. The stacked sieves were placed on a drain bucket. One hole was cut in the lid of the drain bucket while a second hole was cut above the base of the drain bucket. Sediment samples were placed in the top sieve and the sieve column was agitated while water was poured over the sieve column. Sand particles that passed through all of the sieves were retained in the drain bucket. Once the sample was completely sieved, each sieve was weighed. The weight of the sieve and the sample collected in that sieve were recorded. The weight of the sieve was then deducted from the sieve and sample weight to calculate the weight of the sample retained in the sample. Once the weight for each sieved sample was completed, a total weight was calculated

for all of the samples. A relative weight for each size class was then derived by comparing the individual sieve results to the overall total weight of the sample. This process was completed for surface and subsurface samples collected in the project area. The samples were wet-sieved and weighed in the field. Weights were recorded (less tare weight) by size class and a material size-class distribution plotted using RIVERMorph version 3.1 (RIVERMorph LLC, 2005).

#### Bank Erodibility Hazard Index

A Bank Erodibility Hazard Index (BEHI) was used to evaluate streambank erosion potential (D. Rosgen, 2001). The BEHI procedure integrates multiple factors which have a direct impact on streambank stability, including the following parameters.

- Ratio of streambank height to bankfull stage.
- Ratio of riparian vegetation rooting depth to streambank height.
- Degree of rooting density.
- Composition of streambank materials.
- Streambank angle.
- Bank material stratigraphy.
- Bank surface protection afforded by woody debris and vegetation.

The BEHI index incorporated these seven variables into a numerical reach score that was used to rank streambank erosion potential on a scale ranging from very low to extreme. Several bank sites within each reach were evaluated for bank integrity. The number of sites evaluated within each reach was based upon the variability of bank conditions within the reach. Selected sites provided a representative sample of bank conditions throughout the reach.

**Table B-3.** BEHI score and rating matrix (Rosgen, 2001).

Parameter		Very Low	Low	Moderate	High	Very High	Extreme
Bank Height Ratio	Value	1.0 – 1.1	1.11 – 1.19	1.2 – 1.5	1.6 – 2.0	2.1 – 2.8	> 2.8
	Index	1.0 – 1.9	2.0 – 3.9	4.0 – 5.9	6.0 – 7.9	8.0 – 9.0	10
Root Depth Ratio	Value	1.0 – 0.9	0.89 – 0.5	0.49 – 0.3	0.29 – 0.15	0.14 – 0.05	<0.05
	Index	1.0 – 1.9	2.0 – 3.9	4.0 – 5.9	6.0 – 7.9	8.0 – 9.0	10
Weighted Root Density	Value	100 – 80	79 – 55	54 – 30	29 – 15	14 – 5	<5
	Index	1.0 – 1.9	2.0 – 3.9	4.0 – 5.9	6.0 – 7.9	8.0 – 9.0	10
Bank Angle	Value	0 – 20	21 – 60	61 – 80	81 – 90	91 – 119	>119
	Index	1.0 – 1.9	2.0 – 3.9	4.0 – 5.9	6.0 – 7.9	8.0 – 9.0	10
Surface Protection	Value	100 – 80	79 – 55	54 – 30	29 – 15	14 – 10	<10
	Index	1.0 – 1.9	2.0 – 3.9	4.0 – 5.9	6.0 – 7.9	8.0 – 9.0	10

After evaluating the core bank integrity parameters describe in Table B-3, bank material composition factors were considered. Depending upon bank materials, BEHI score were adjusted up or down (Rosgen, 2001). Banks comprised of bedrock, boulders and cobble had very low erosion potential. Banks composed of cobble and/or gravel with a high fraction of sand had increased erosion potential. Stratified banks containing layers of unstable material also



displayed greater erosion potential. After adjusting the core BEHI score for bank material composition factors, a final BEHI score and rating was derived (Table B-4).

**Table B-4.** BEHI score and rating following bank materials adjustment.

Rating	Very Low	Low	Moderate	High	Very High	Extreme
Score	5-9.5	10-19.5	20-29.5	30-39.5	40-45	46-50

The BEHI data will also be used to develop erosion rates for the respective reaches in the final design phase. Bank pins were installed at select sites and will be re-measured in 2006 to validate the predicted bank condition using the BEHI method.

## **B.2.3 Data Processing, Analysis and Reporting**

### **B.2.3.1 Raw Data Processing and Reach Summaries**

Total Station survey data was processed and analyzed in RIVERMorph<sup>®</sup> version 3.1 (RIVERMorph LLC, 2005). RIVERMorph<sup>®</sup>, a geomorphic stream channel assessment and data storage software, merged all aspects of the surveys by transcribing the total station data from x, y, and z coordinates to station and elevation formats. The software was used to process and analyze data and produce channel reach statistics.

Cross-section data and longitudinal profile data were plotted and summary statistics generated in RIVERMorph<sup>®</sup> and Microsoft Excel. Sediment data including pebble counts, RSI data, and pavement and sub-pavement samples were also analyzed. Dimensionless ratios were computed automatically for multiple variables using RIVERMorph<sup>®</sup> and Microsoft Excel.

### **B.2.3.2 Bed Resistance and Channel Hydraulics**

Streambank and channel bed characteristics are the primary parameters influencing flow resistance and ultimately the conveyance capacity of a channel. Investigating existing channel conditions in both reference and other reaches provides insights to channel resistance properties. Incorporating channel resistance variables in the design phase of this project will be necessary to investigate channel stability, conveyance capacity, and sediment transport processes (see Appendix C). It is important to understand the flow characteristics of the existing and design condition in order to anticipate likely channel responses to a range of environmental conditions.

Two models were used to evaluate bed resistance and channel hydraulics. The U.S. Army Corps of Engineer's Hydrologic Engineering Center River Analysis System version 3.1.2 (HEC-RAS) was used to model existing channel conditions and validate bankfull discharge. HEC-RAS performs one-dimensional water surface profile calculations for steady gradually varied flow. The basic computational procedure of HEC-RAS is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by change in velocity head).

WinXSPRO (WEST Consultants, 1998) was also used to analyze cross-section data for geometric and hydraulic parameters. The theoretical background for analyzing channel cross-

section data is derived from the basic continuity, momentum, and energy equations of fluid mechanics (WEST Consultants, 1998). Manning's equation was used as the roughness coefficient in the model. Discharge (cfs) measured at USGS gaging stations on the day of the specific surveys were used to calibrate the hydraulic models.

Bankfull channel total shear stress was calculated and compared to the Shields diagram which describes the relationship between critical shear stress and incipient motion of sediment grains along the streambed. Two curves were used including the standard Shields curve and a modified Shields curve that is based on the ratio of the  $D_{84}$  to  $D_{35}$  of the bed material (D. Rosgen, 2001).

### **B.3 CLARK FORK RIVER EXISTING CONDITIONS**

#### **B.3.1 Introduction**

This section describes the existing conditions of the CFR within CFR3 and CFR1. Section B.3.2 summarizes the results of a hydrology and flood series analysis performed for the CFR at Turah Bridge and above Missoula (downstream of Milltown Dam). Sections B.3.3 through Section B.3.10 include the summary data and stream reach assessments.

#### **B.3.2 Hydrology**

The CFR watershed is located west of the Continental Divide with most of the headwater streams originating along the Continental Divide. A majority of the precipitation occurs as snow that typically melts between April and June producing snowmelt runoff dominated hydrographs. Mean annual precipitation ranges from 14 inches near Milltown Dam to 50 inches at the Continental Divide (USDA Soil Conservation Service, 1990).

The annual hydrograph of CFR generally exhibit one peak flow period that occurs in May or June in response to snowmelt runoff. Snow pack characteristics, air temperature, and periodic rain events influence the timing and duration of spring runoff. The CFR at Turah Bridge (CFR3) typically flows less than 1,000 cfs from mid-July through March and experiences baseflow (discharge less than 700 cfs) conditions from early August through early October, and from mid-December to mid-January. Flows typically exceed 2,000 cfs from early May through late June with peak flows occurring in early June. The CFR above Missoula (CFR1) typically flows less than 2,000 cfs from August through March with baseflow conditions (discharge less than 1,500 cfs) from mid August through early October, and from early December through February. Flows typically exceed 8,000 cfs from mid-May through late June with the highest flow typically occurring during the first week of June. Low flow conditions in the CFR in August and September are partially attributed to surface water appropriations and diversions for a variety of beneficial uses.

A detailed hydrology and flood series analysis of the CFR was prepared by WWC and RDG in cooperation with the USGS and EMC<sup>2</sup> (see Appendix A). Flood magnitudes for selected recurrence intervals were determined from a flood frequency curve using the log-Pearson Type III distribution method as outlined in Bulletin #17B Guidelines for Determining Flood Flow Frequency (U.S. Department of the Interior Geological Survey, 1982). Two approaches were



used to determine bankfull discharge for the BFR and CFR upstream of Milltown Dam: analysis of flood frequency using historical streamflow gaging records, and field calibration of bankfull discharge at the USGS gaging stations. The selected bankfull and flood magnitudes for selected recurrence intervals are presented in Table B-5.

**Table B-5.** Selected bankfull ( $Q_{bf}$ ) and flood flow values (cfs) for the CFR at Turah, and CFR above Missoula USGS gages. Values were rounded to the nearest 100 cfs.

USGS Station	Recurrence Interval (yrs)						
	$Q_{bf}$	$Q_2$	$Q_{10}$	$Q_{25}$	$Q_{50}$	$Q_{100}$	$Q_{500}$
CFR at Turah	3,200	4,600	9,700	12,600	14,700	16,900	22,100
CFR above Missoula	10,400	14,600	25,700	30,800	34,400	37,800	45,200

### B.3.3 Historical Channel Regimes and Land Uses

#### B.3.3.1 Historical Channel Regimes

The current morphological states of the CFR are reflective of both natural processes and human-induced impacts in the river corridor. Historically and prior to development, the CFR valley upstream of Milltown Dam to Turah Bridge was characterized by multiple river terraces developed within a broad belt width. Holocene alluvial terraces and wide floodplains were the principal depositional features with glacial terraces of Pleistocene age bounding the valley sides. Floodplain widths upstream from the confluence with the BFR ranged from approximately 1,600 ft to 3,000 ft. At the most confined point in the vicinity of the present day Duck Bridge, a natural constriction of the floodplain existed, formed by a Pleistocene terrace on the northern boundary and an opposing fluvial terrace on the southern boundary. This natural constriction reduced the floodplain width to nearly 1,500 ft at the Duck Bridge site, substantially reducing the floodplain area and meander belt width of the CFR.

#### B.3.3.2 Land Uses History

Land uses in the CFR watershed date to the mid-1800s when mining, agriculture, and grazing were pursued by early settlers (see Appendix D for a more complete description of historical watershed conditions and early land uses in the watershed). Plentiful water, rich soils, and fertile alluvial valleys were judged as prime conditions for agriculture and grazing. Governor Isaac Stevens leader of the 1853 expedition to survey a route from Fort Benton to Fort Walla Walla, noted, “it will not be many years before the progress of settlements will establish its superiority as an agricultural region” (Stevens, 1856). Gold strikes on Gold Creek as well as placer and hydraulic mining in the headwaters of the CFR were underway by 1852 and well-established by the mid-1860s. Construction of the Military Road from 1860 to 1863, necessitated building fords across the main stem river and tributaries, constructing bridges, and corduroying low-lying wetland areas. These activities required rock blasting, land clearing, and channel modifications on the BFR and CFR rivers as well as side tributaries joining the CFR upstream of the confluence. By the time the Military Road was completed in 1863, herders were moving flocks of sheep numbering in the thousands through the CFR valley.

Construction of the Northern Pacific Railroad and the Chicago, Milwaukee, and St. Paul Railway (CMSPR) between the 1880s and 1908 further constrained the river network. Bracketing both sides of the CFR, the railroads were constructed to limit channel length while also minimizing interactions with the channel. The Northern Pacific Railroad located on the northern and eastern side of the CFR had limited interactions with the CFR. Conversely, the CMSPR railroad bed was placed on the southern and western side of the channel alignment and interacted extensively with the CFR, especially downstream of Turah. The established railway narrowed the valley bottom and truncated channel segments, disconnecting meanders and floodplain area from the active river corridor.

Construction of Milltown Dam between 1906 and 1907, and increasing resource extraction in the watershed substantially modified the CFR and BFR in the vicinity of Bonner. The dam disconnected river processes in the vicinity of the rivers' confluence. Sediment deposition behind the dam significantly accelerated during the 1908 flood of record when millions of cubic yards of mining and milling wastes and clean sediment were delivered to the reservoir.

Continued development in the CFR and BFR corridors has included the construction of Interstate 90 and Highway 200; residential floodplain development and associated flood control projects (e.g. Turah levee); mining; upland and riparian logging; and floodplain agricultural development.

The river system has generally responded to development effects that have caused increased sediment loading, created a narrower valley bottom, and increased stream energy by braiding. Channel braiding has also been exacerbated by the poor riparian condition that is increasingly represented by monoculture assemblages of noxious weeds that provide poor bank stability and cover, and displace more beneficial native species. As native plant species are replaced by noxious weeds with shallow rooting depths and limited woody debris recruitment potential, streambanks are less resistant to scour and therefore contribute more sediment to the channel network. Accelerated sediment delivery overwhelms the channel's ability to mobilize the sediment load and the channel initiates channel widening. Eventually channel braiding occurs as the bedload overwhelms the channel competence. This pattern of bank erosion, channel widening, and braid formation is common on the CFR from Turah Bridge downstream to Milltown reservoir. Infrequent high magnitude floods and periodic ice floes further exacerbate channel instability, promoting a braided channel regime. Despite these processes, the CFR has exhibited the resilience to return to a single thread meandering channel pattern as riparian vegetation encroaches on the channel and stabilizes floodplain sediment. This planform is exhibited in CFR3-B where the river has maintained a single thread channel since at least 1937.

#### **B.3.4 CFR3-A Existing Conditions**

CFR3 was characterized as an Alluvial Valley (Montgomery and Buffington, 1993) or Type VIII valley according to the Rosgen classification system (Rosgen, 1996). These valley types are associated with multiple Holocene terraces and wide floodplains which serve as the principal depositional features. While a variety of channel morphologies can exist, the predominant channel forms include slightly entrenched, meandering forms with riffle-pool bed morphology. These types are classified as C stream types (Rosgen, 1996) or Pool-Riffle types (Montgomery and Buffington, 1993). Lateral migration across the active floodplain, over time, while

maintaining the average hydraulic geometry relationships of the bankfull channel, is a dominant physical process in forming floodplain morphology. Lateral migration rates are in part controlled by riparian vegetation condition and bank material composition. Direct and indirect disturbances, in addition to natural watershed perturbations, can accelerate channel succession, converting predominantly meandering systems into braided, multiple channel, high sediment supply regimes.

The following sections discuss the existing reach conditions of CFR3-A.

### B.3.4.1 Planform

The planform morphology of CFR3-A was assessed using field and remote sensing data including 1937, 1956, 1966, 2000, 2003, and 2004 aerial photo series. The dominant channel classified as a braided type characterized by multiple, unstable threads, wide, shallow cross-sections, and convergent-divergent bedforms. Bankfull channel widths ranged from 633 ft to 779 ft with an average value of 708 ft (Table B-6). Sinuosity measured 1.03, indicating a channel slope approximating the average valley slope.

**Table B-6.** The existing planform channel dimensions in CFR3-A. Mean values (range).

Channel Type	Sinuosity	Bankfull Width (ft)	Entrenchment Ratio	Meander Belt Width (ft)	Meander Length (ft)	Radius of Curvature (ft)
D3	1.03	708 (633-779)	1.86	n/a	n/a	n/a

CFR3-A has remained extensively braided since 1937. Review of the available photo series indicated a highly unstable channel type with frequent, annual shifts in dominant bed locations and minimal variation in planform characteristics. Direct impacts to the channel included the historical railroad grade located on the south side of the active floodway. Over the past seventy years, the CFR has periodically intercepted the railroad grade fillslope. Channel belt width has diminished over time, from a maximum of 1,300 ft in 1937 to 500 ft in 2000. The channel is presently aligned against the railroad grade in numerous locations. Localized bed degradation is apparent along these sections.

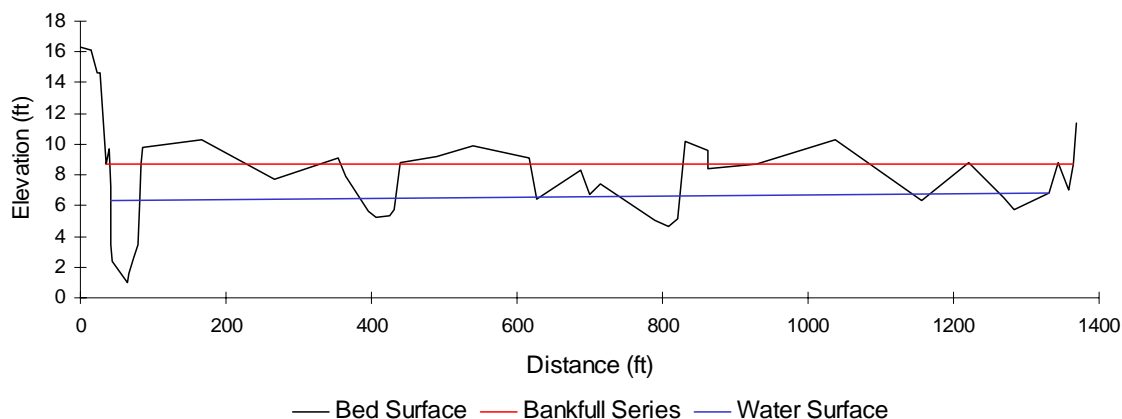
### B.3.4.2 Channel Cross-Sections

Three cross-sections were surveyed in CFR3-A. Due to the absence of channel-spanning pools in the braided reach, all cross-sections were surveyed in riffle habitat units. Bankfull channel widths ranged from 633 ft to 779 ft, with corresponding width-to-depth ratios ranging from 385 to 451, respectively. Maximum channel depths ranged from 5.4 ft to 7.4 ft with an average value of 6.4 ft. Average bankfull cross-sectional area was 1,208 ft<sup>2</sup>, ranging from 1,128 ft<sup>2</sup> to 1,361 ft<sup>2</sup>.

**Table B-6.** The existing channel cross-section dimensions in CFR3-A. Average value (range).

Habitat Type (n)	Bankfull width (ft)	Average depth (ft)	Width-to-depth ratio	Maximum depth (ft)	Cross-sectional area (ft <sup>2</sup> )
Riffle (3)	708 (633-779)	1.7 (1.6-1.8)	427 (385-451)	6.4 (5.4-7.4)	1,208 (1,128-1,361)

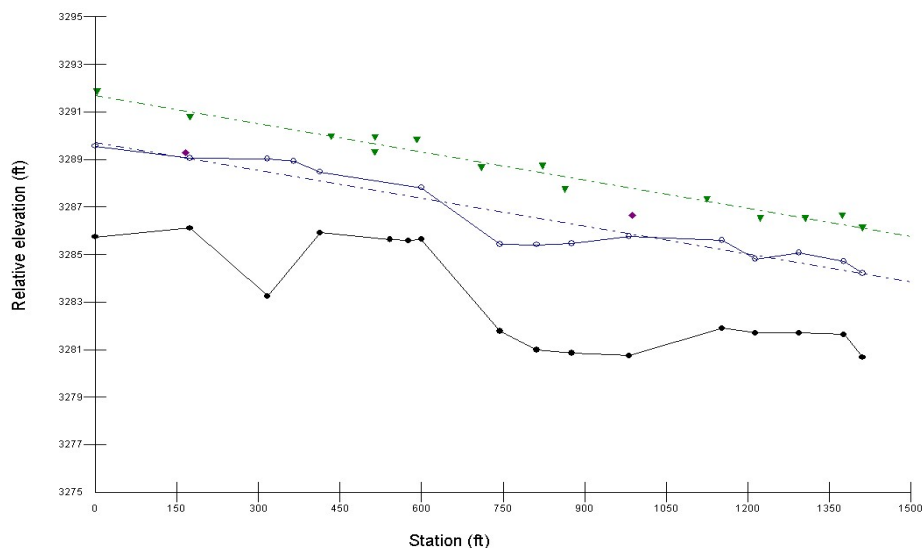
The channel cross-section data reflected the excessively wide, shallow channel morphology resulting from in-channel and upstream sediment delivery. High sediment supply and erodible banks favor formation of a braided channel, as frequent deposition of bars causes lateral channel shifting across the channel bed (Leopold and Wolman, 1957; Leopold et al., 1964). Figure B-3 displays a typical cross-section depicting the dominant channel form in CFR3-A.



**Figure B-3.** Valley cross-section depicting the braided, multiple channel regime in CFR3-A.

#### B.3.4.4 Channel Profile

A detailed longitudinal profile was surveyed along 1,300 ft of channel to characterize existing bed morphology associated with the braided channel regime. Figure B-4 presents the longitudinal profile graph depicting the dominant channel thalweg, water surface, and bankfull features. Best-fit trend lines were applied to the water surface and bankfull data.



**Figure B-4.** Longitudinal channel profile graph depicting dominant bed morphology, water surface facet slopes, and bankfull features within CFR3-A. The green points represent the bankfull floodplain with a best-fit line, the blue points are the water surface with a best-fit line, and the black points represent the thalweg.

Longitudinal channel profile data results are summarized in Table B-7 and B-8. Average water surface slope was 0.0039 ft/ft. Average riffle slope was 0.01 ft/ft, approximately 2.5 times steeper than the average water surface slope.

**Table B-7.** Summary of longitudinal channel profile data (ft).

Valley Slope	Ave. Water Surface Slope	Ave. Riffle Slope	Ave. Pool Slope	Pool to Pool Spacing (ft)	Pool Length (ft)
0.004	0.0039	0.0100	n/a	n/a	n/a

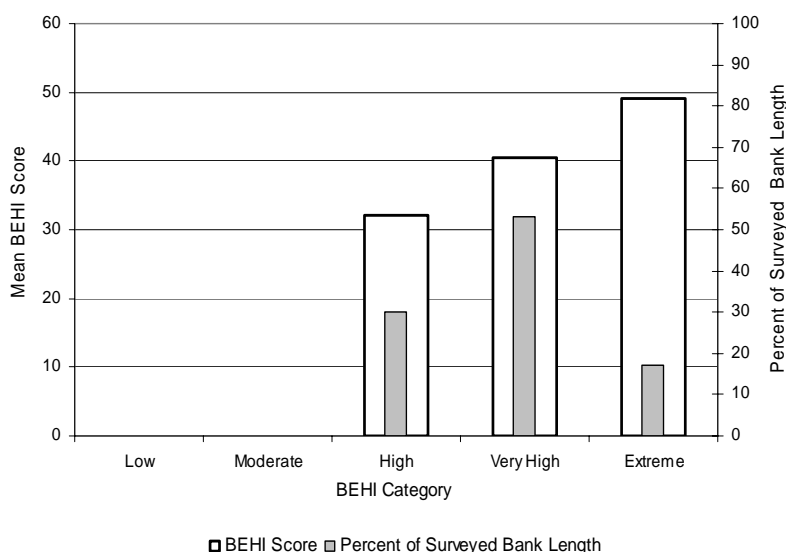
Bed morphology was generally characterized by a closely spaced series of riffles/runs and scour pools. Mid-channel, lateral, and transverse bars were common, a majority of which were unvegetated and mobile during higher flow regimes. Pools occurred as a minor habitat component and were associated with small diameter, unstable woody debris aggregates, localized bank scour, and converging flow lines.

**Table B-8.** Summary of Longitudinal Channel Profile Dimensionless Ratios.

Riffle Slope / Ave. Slope	Pool Slope / Ave. Slope	Pool Length / Bankfull Width	Pool to Pool Spacing / Bankfull Width
2.56	n/a	n/a	n/a

#### B.3.4.5 Bank Integrity

The bank integrity analysis included an evaluation of five bank sites with a total surveyed bank length of approximately 3,000 ft within CFR3-A. The five sites represented the average bank conditions within the reach (Figure B-5).



**Figure B-5.** BEHI scores and ratings for representative bank condition in CFR3-A.

In general, bank height ratios (bank height/bankfull height) were less than 2.0, indicating significant degree of vertical entrenchment of the bankfull channel relative to the adjacent

floodplains and low terraces. These results reflect the generally entrenched condition of the channel adjacent to the historical railroad grade on the south side of the floodway. Rooting depth ratio ranged from 0.1 to 0.6 with a mean of 0.4. Weighted root density included values of approximately 2, 13, and 35. Bank angles ranged from 60 to 90 degrees and surface protection from 10 to 80 percent with an average of 42%. Bank material composition was primarily sand with no stratification (Figure B-6). Bank erosion potential at all sampled sites ranged from high to extreme. Numeric BEHI ratings ranged from 30.8 at Site 2 to 49.0 at Site 4.



**Figure B-6.** Typical bank condition in CFR3-A. Note lack of woody vegetation and dominance of noxious weed s.

Thirty percent (30%) of the surveyed banks rated high in terms of bank erosion potential, 53% very high, and 17% extreme. The frequency of eroding banks appeared to correlate with degraded vegetation conditions on the floodplains and low terraces.

#### **B.3.4.6 Bed Resistance and Channel Hydraulic Analysis**

Streambank and channel bed characteristics are the primary channel characteristics influencing flow resistance and the conveyance capacity of a channel. Riffle cross-section data were analyzed using WinXSPRO (WEST Consultants, 1998) and HEC-RAS (USACE, 2004). Bankfull channel total shear stress was calculated and compared to the Shields diagram which describes the relationship between critical shear stress and incipient motion of grains along the streambed. Two curves were used including the standard Shields curve and a modified Shields curve that is based on the ratio of the  $D_{84}$  to  $D_{35}$  of the bed material (D. Rosgen, 2001).

CFR3-A was characterized by very coarse gravel substrate, with particles ranging in size from 1.9 mm (coarse sand) to a maximum particle size of 256 mm (large cobble). Hydraulic modeling and incipient motion results for a typical cross-section in CFR3-A are presented in Table B-9.



**Table B-9.** Hydraulic and incipient motion modeling results for bankfull discharge.

Velocity (ft/s)	Manning's n-value	Total shear stress (lbs/ft <sup>2</sup> )	Grain Diameter (mm)	Size Class (% finer than)
3.7	0.036	0.41	80-90 <sup>1</sup> 20-30 <sup>2</sup>	D <sub>60-65</sub> D <sub>22-25</sub>

<sup>1</sup> Modified Shields curve (D. Rosgen, 2001)

<sup>2</sup> Shields curve

Comparing the results of the hydraulic modeling to the modified Shields curve and composite sediment gradation data for CFR3-A, the channel is capable of initiating motion of an 80-90 mm particle (D<sub>60-65</sub>) during bankfull discharge. The standard Shields curve predicts a much smaller particle size class, approximately 20-30 mm (D<sub>22-25</sub>).

The results of the hydraulic modeling were also compared to the RSI results presented in Table B-10. The geometric mean of the largest mobile particles sampled was 118 mm. When compared to the cumulative particle size distribution from the riffle sediment gradation curve, an RSI score of 81 was derived.

**Table B-10.** Channel particle size distribution and riffle stability index (RSI) results.

Composite Gradation (mm)						RSI	
D <sub>16</sub>	D <sub>35</sub>	D <sub>50</sub>	D <sub>84</sub>	D <sub>95</sub>	D <sub>100</sub>	Geometric Mean (mm)	Score
1.9	38	56	109	157	256	118	81

The results of this analysis applying the modified Shields curve indicate that the current channel regime is capable of initiating motion of particles ranging in size from 80 to 118 mm (small cobble), or the D<sub>60</sub>-D<sub>81</sub> size class of the available bed material during bankfull discharge. The standard Shields curve predicted a much smaller size class ranging from 20 to 30 mm, or the D<sub>22</sub>-D<sub>25</sub> of the bed material.

### B.3.5 CFR3-B Existing Conditions

#### B.3.5.1 Planform

The planform morphology of CFR3-B was characterized using field and remote sensing data including 1937, 1956, 1966, 2000, 2003, and 2004 aerial photos. While occurring in the same valley type as CFR3-A, channel morphology was significantly different and consisted of a meandering, primarily single-thread channel typical of a Pool-Riffle channel type (Montgomery and Buffington, 1993) or C4 stream type (Rosgen, 1996). Prior to the field survey, a detailed air photo analysis was conducted to evaluate reach stability over time. While the channel has displayed dynamic conditions throughout the analysis period, the average channel dimensions have remained similar amidst ongoing lateral channel migration and meander cutoff development. This observation, and the persistence of a dominant, meandering planform from 1937 to 2004, indicated that this reach was generally more stable than CFR3-A and CFR3-C. The reach was therefore defined as a reference reach for the purpose of quantitatively describing a functioning meandering, riffle-pool channel type.

The reach analysis included two meander wavelengths situated between the downstream end of CFR3-A and upper end of CFR3-C. The meander geometry of the upstream meander sequence did not change significantly between 1937 and 2004. However, lateral migration was active in the second meander and included a northerly migration of approximately 500 ft from 1937 to 2004. Channel width remained markedly similar over the time series aerial photos despite lateral migration. Downstream, a meander cutoff occurred between 1966 and 2000 as the dominant channel migrated down valley, leading to the development of a chute cut-off channel across the active floodplain. The chute channel captured a majority of the dominant channel between 1956 and 1966, perhaps during the 1964 flood. By 1966, the entire main channel avulsed and was captured by the chute channel, where it has remained in place since 2000. Similar to the upstream meander sequence, channel width ranged from 150 ft to 200 ft from 1937 to 2004, indicating relative stability when compared to the upstream and downstream braided regimes in CFR3-A and CFR3-C.

In 2004, channel sinuosity measured 1.21. Bankfull channel widths for riffle units ranged from 138 ft to 206 ft with an average value of 183 ft. Meander belt width averaged 687 ft with a range of 625 ft to 750 ft. Radius of curvature ranged from 406 ft to 469 ft, with a mean of 437 ft (Table B-11).

**Table B-11.** The existing planform channel dimensions in CFR3-B. Mean values (range).

Channel Type	Sinuosity	Bankfull width (ft)	Meander belt width (ft)	Meander length (ft)	Radius of curvature (ft)
C4	1.21	183 (138-206)	687 (625-750)	1,755 (1,510-2,000)	437 (406-469)

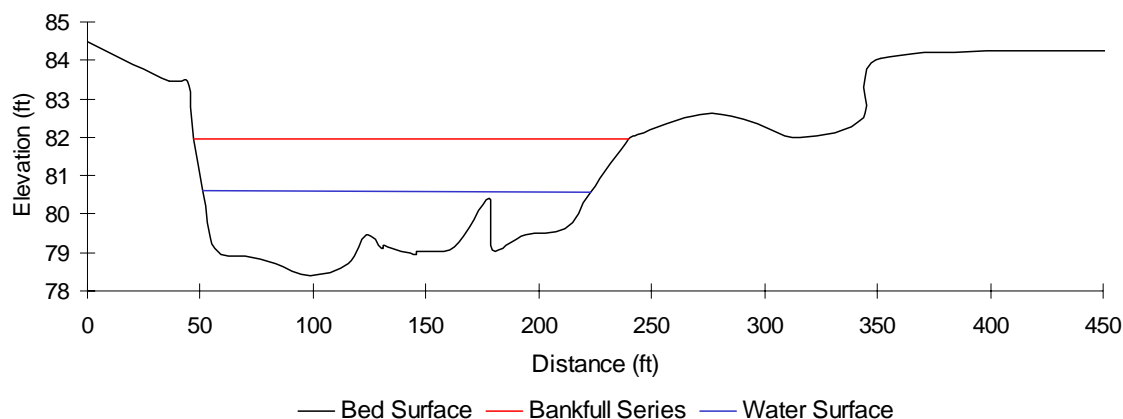
### B.3.5.2 Channel Cross-Sections

A total of eight cross-sections were surveyed in CFR3-B. Two cross-sections were surveyed in each habitat type to characterize riffle, pool, run, and glide morphology. Bankfull riffle habitat unit widths ranged from 138 ft to 206 ft, with corresponding width-to-depth ratios ranging from 37 to 77, respectively (Table B-12). Maximum riffle depths ranged from 3.9 ft to 6.2 ft with an average value of 4.9 ft. Average bankfull cross-sectional area for riffle habitat units was 572 ft<sup>2</sup>, ranging from 519 ft<sup>2</sup> to 646 ft<sup>2</sup>.

**Table B-12.** The existing channel dimensions in CFR3-B. Average value (range).

Habitat Type (n)	Bankfull width (ft)	Average depth (ft)	Width-to-depth ratio	Maximum depth (ft)	Cross-sectional area (ft <sup>2</sup> )
Riffle (2)	183 (138-206)	3.2 (2.7-3.8)	60 (37-77)	4.9 (3.9-6.2)	572 (519-646)
Pool (2)	191 (170-213)	3.4 (2.9-3.8)	n/a	7.5 (7.3-7.6)	648 (492-804)
Run (2)	151 (126-167)	3.3 (2.9-3.7)	n/a	6.2 (3.7-7.8)	503 (384-616)
Glide (2)	216 (156-327)	3.1 (2.0-3.7)	n/a	4.7 (4.3-4.9)	624 (541-660)

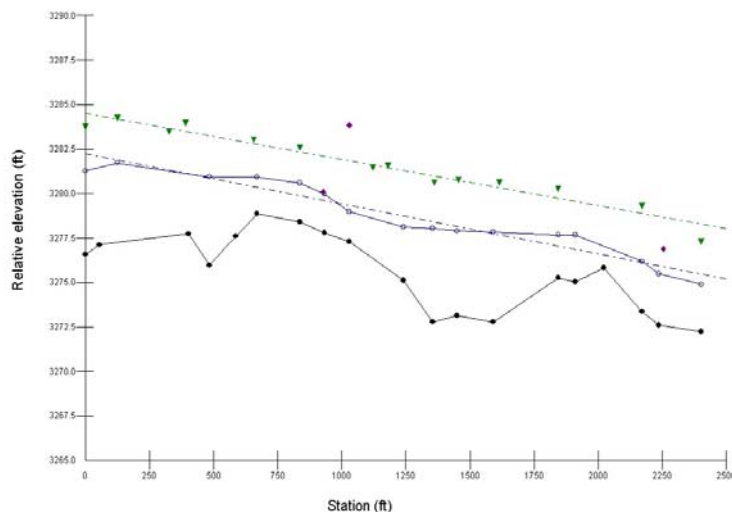
Pool habitat units were generally wider and deeper than riffle units, as expected. Bankfull pool width ranged from 170 ft to 213 ft. with maximum depths of 7.3 ft to 7.6 ft. Average bankfull cross-sectional area was 648 ft<sup>2</sup>, approximately 13% greater than riffle habitat units. Glide habitat units corresponded to pool tailouts and were generally wider and shallower than riffle, pool and run habitat units. Bankfull widths for glides ranged from 156 ft to 327 ft, with average depths ranging from 2.0 ft to 3.7 ft. Runs were identified as areas where the profile transitioned from riffle to pool habitat units, and had the least cross-sectional area of all sampled habitat units (average of 503 ft<sup>2</sup>). Bankfull run widths ranged from 126 ft to 167 ft with mean depths of 2.9 ft to 3.7 ft.



**Figure B-7.** Cross-section depicting the typical channel morphology (riffle habitat unit) in CFR3-B.

### B.3.5.3 Channel Profile

Longitudinal profile data were collected on a 2,400 ft representative reach of CFR3-B (Figure B-8). Features including channel thalweg, water surface, and bankfull floodplains were surveyed to characterize the channel profile. Bedform morphology was characterized by an undulating thalweg transitioning between pool and riffle sequences. Pools were formed primarily by flow through meander bends with bank vegetation consisting of the cottonwood/red osier dogwood (*Populus trichocarpa*/*Cornus stolonifera*) habitat type (Hansen et al., 1995).



**Figure B-8.** Longitudinal channel profile graph depicting dominant bed morphology, water surface facet slopes, and bankfull features within CFR3-B. The green points represent the bankfull floodplain with a best-fit line, the blue points are the water surface with a best-fit line, and the black points represent the thalweg.

The average energy slope of the reach measured 0.0025 ft/ft with average riffle and pool slopes of 0.0066 ft/ft and 0.0005 ft/ft, respectively (Table B-13). The ratios of riffle and pool slopes to average slope were 2.64 and 0.20, respectively (Table B-14). The dimensionless ratios reflect the natural transition between steeper riffle slopes and flat pool slopes. Bedforms associated with the Pool-Riffle or C stream type naturally undulate to dissipate energy while forming and maintaining complex and diverse aquatic habitats. The undulating profile also maintains the vertical stability of the channel through scour along a meander arc and deposition at end of the meander or pool tailout (glide habitat unit).

**Table B-13.** Summary of channel longitudinal profile data.

Valley Slope	Ave. Water Surface Slope	Ave. Riffle Slope	Ave. Pool Slope	Pool to Pool Spacing (ft)	Ave. Pool Length (ft)
0.003	0.0025	0.0066	0.0005	689	375

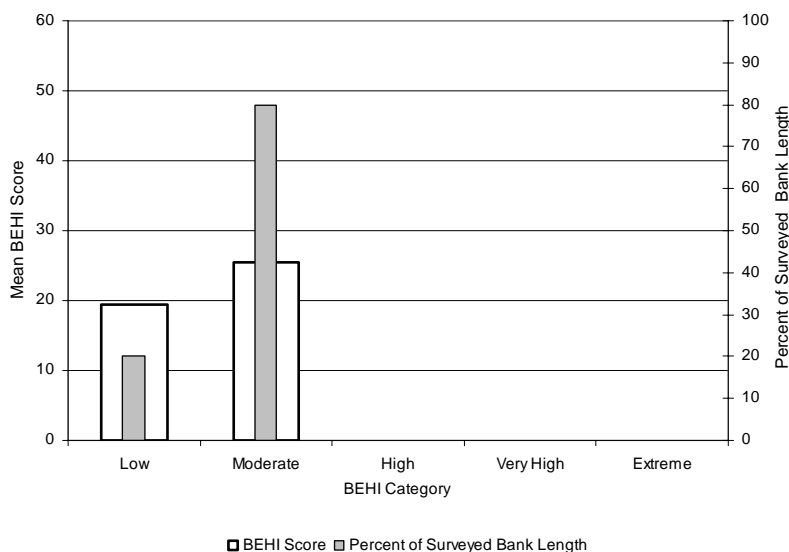
Large woody debris aggregates were commonly associated with the meanders, causing localized flow convergence and scour along the bank face. On average, pools were 375 ft long with a spacing of 689 ft. This equated to a pool to pool spacing to bankfull width ratio of 3.8 (Table B-14).

**Table B-14.** Summary of longitudinal channel profile dimensionless ratios.

Riffle Slope / Ave. Slope	Pool Slope / Ave. Slope	Pool Length / Bankfull Width	Pool to Pool Spacing / Bankfull Width
2.64	0.20	2.1	3.8

### B.3.5.4 Bank Integrity

The bank integrity analysis included an evaluation of three bank sites with a total surveyed bank length of approximately 2,000 ft within CFR3-B (Figure B-9). The surveyed sites were representative of the average streambank conditions in CFR3-B.



**Figure B-9.** BEHI scores and ratings for representative bank condition sites in CFR3-B.

Bank height ratios ranged from 1.2 to 1.4. Root depth ratio ranged from 0.2 to 0.6 with corresponding weighted root density values of 8, 31, and 2. Bank angles ranged from 60 to 80 degrees and surface protection from 39 to 70 percent. Bank material composition consisted of gravel with little to no sand or unstable strata.



**Figure B-10.** Photos of representative streambank conditions within CFR3-B.

Bank erosion potential rated low to moderate with numeric BEHI of 19.5 at Site 1, 21.4 at Site 2 and 29.5 at Site 3. The sites with the lowest and highest values are depicted in Figure B-10. The most stable site (lowest BEHI rating) was characterized by streambank and riparian vegetation consisting of the cottonwood/red osier dogwood habitat type (Hansen et al., 1995). The bank surface was protected by dense, overhanging woody shrub species that provided cover and shade

along the lateral margins of the channel. The most unstable site (highest BEHI rating) consisted of unconsolidated Belt series alluvium and a riparian zone dominated by a grass understory and black cottonwood overstory. Bank surface protection was minimal (29%) and associated with overhanging sod mats void of riparian shrubs and root masses. In general, areas of low bank integrity were associated with residential land uses that converted the historical shrub community to grass dominated types.

### B.3.5.5 Bed Resistance and Channel Hydraulics

CFR3-B was characterized by coarse gravel substrate, with particles ranging in size from 1.0 mm (very coarse sand) to a maximum particle size of 256 mm (large cobble). Hydraulic modeling and incipient motion results for a typical cross-section in CFR3-B are presented in Table B-15.

**Table B-15.** Hydraulic and incipient motion modeling results for bankfull discharge.

Velocity (f/s)	Manning's n-value	Total shear stress (lbs/ft <sup>2</sup> )	Grain Diameter (mm)	Size Class (% finer than)
6.31	0.030	0.65	95-105 <sup>1</sup> 35-40 <sup>2</sup>	D <sub>85-90</sub> D <sub>52-55</sub>

<sup>1</sup> Modified Shields curve (D. Rosgen, 2001)

<sup>2</sup> Shields curve

Comparing the results of the hydraulic modeling to the modified Shields curve and composite sediment gradation data for CFR3-B (Table B-16), the channel is capable of initiating motion of a 95-105 mm particle (D<sub>85</sub> - D<sub>90</sub> particle size class) during bankfull discharge. The results of the hydraulic modeling were also compared to the RSI results presented in Table B-16. The geometric mean of the largest mobile particles sampled was 174 mm. When compared to the cumulative particle size distribution from the riffle sediment gradation curve, an RSI score of 98 was derived.

**Table B-16.** Particle size distribution and riffle stability index (RSI) results.

Composite Gradation						RSI	
D <sub>16</sub>	D <sub>35</sub>	D <sub>50</sub>	D <sub>84</sub>	D <sub>95</sub>	D <sub>100</sub>	Geometric Mean	Score
1	14	30	91	129	256	174	98

A third data set was also included in the analysis. Sieve analysis results from a depositional bar sample were tallied and the two largest particles averaged. Results indicated an average largest size particle of 95 mm, which compared well with the predicted particle size range from the modified Shields curve (95-105 mm).

The combined results applying the modified Shields curve and RSI and bar sample data indicated that the current channel regime is capable of initiating motion of particles ranging in size from 95 to 174 mm (small cobble), or the D<sub>85</sub> - D<sub>98</sub> size class of the available bed material during bankfull discharge. The standard Shields curve predicted a much small particle size class ranging from 35-40 mm, or the D<sub>52</sub> - D<sub>55</sub> of the bed material. Based on the combined results of the other methods, the standard Shields curve likely under-predicted grain size diameter for the modeled critical shear stress values.



### B.3.6 CFR3-C Existing Conditions

Similar to CFR3-A, the lower reach of CFR3 upstream of Milltown Reservoir classified as a braided channel type, characterized by multiple, unstable threads and wide, shallow cross-sections. The lower extent of the reach is subject to backwater conditions imposed by Milltown Dam. Perhaps one of the most influential events shaping the current condition of CFR3-C was the flood of 1908 that was estimated at 48,200 cfs. Driven by 33 consecutive days of rain on snowmelt conditions, the backwater effect imposed on the CFR extended approximately 3,100 ft upstream into CFR3, completely inundating CFR3-C and the lower end of CFR3-B. While the extent of headward aggradation resulting from this event is not known, sediments were extensively deposited in the active channels and floodplains, burying historical fluvial terraces. The degree and extent of valley aggradation varied throughout the lower section of CFR3-C. Historical tree stumps exposed and surveyed during the drawdown of Milltown Dam in August 2004 were located by as much as four to six feet below the current floodplain elevation in CFR3-C. The degree to which the 1908 flood event affected the morphology of the CFR in the vicinity of CFR3-C is uncertain, but it is plausible that the system was sensitized prior to the flood and responded through aggradation and accelerated channel migration.

#### B.3.6.1 Planform

Bankfull channel widths ranged from 633 ft to 779 ft with an average value of 708 ft (Table B-17). Sinuosity measured 1.03, indicating a channel slope approximating the average valley slope.

**Table B-17.** Existing planform channel dimensions in CFR3-C. Mean values (range).

Channel Type	Sinuosity	Bankfull Width (ft)	Entrenchment Ratio	Meander Belt Width (ft)	Meander Length (ft)	Radius of Curvature (ft)
D4	1.15	475 (400-529)	2.11	n/a	n/a	n/a

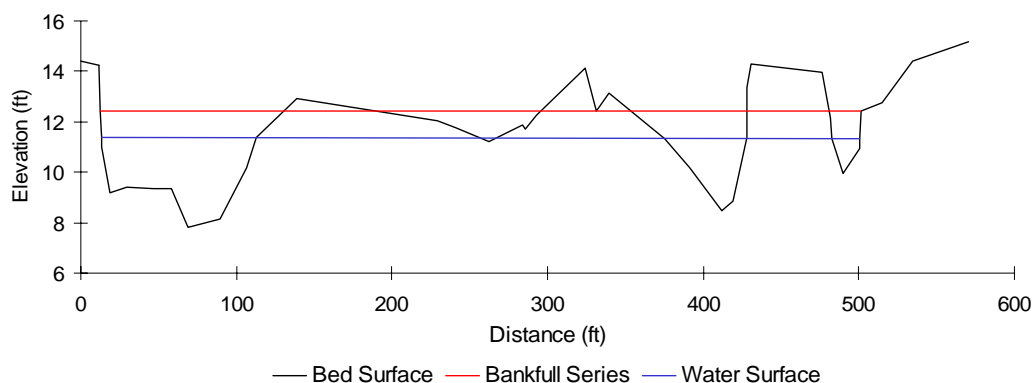
#### B.3.6.2 Channel Cross-Sections

Three cross-sections were surveyed in Reach CFR3-C. Similar to CFR3-A, the reach lacked suitable pool habitat and all surveyed cross-sections were completed in riffle habitat units. The lower cross-section was captured approximately 1,000 ft upstream of Duck Bridge. Bankfull channel widths ranged from 400 ft to 529 ft, with corresponding width-to-depth ratios ranging from 240-220, respectively (Table B-18). Maximum channel depths ranged from 5.0 ft to 8.6 ft with an average value of 6.3 ft. Average bankfull cross-sectional area was 1,076 ft<sup>2</sup>, ranging from 729 ft<sup>2</sup> to 1,291 ft<sup>2</sup>.

Channel cross-sections were comprised of multiple threads separated by fine gravel bars that appeared mobile with increasing streamflows. The bars were largely unvegetated, with the exception of annual grasses and noxious weeds. Channel and bank material composition was also markedly finer than CFR3-B and CFR3-A. Figure B-11 displays a typical cross-section depicting the dominant channel form.

**Table B-18.** The existing cross-section dimensions in CFR3-C. Average value (range).

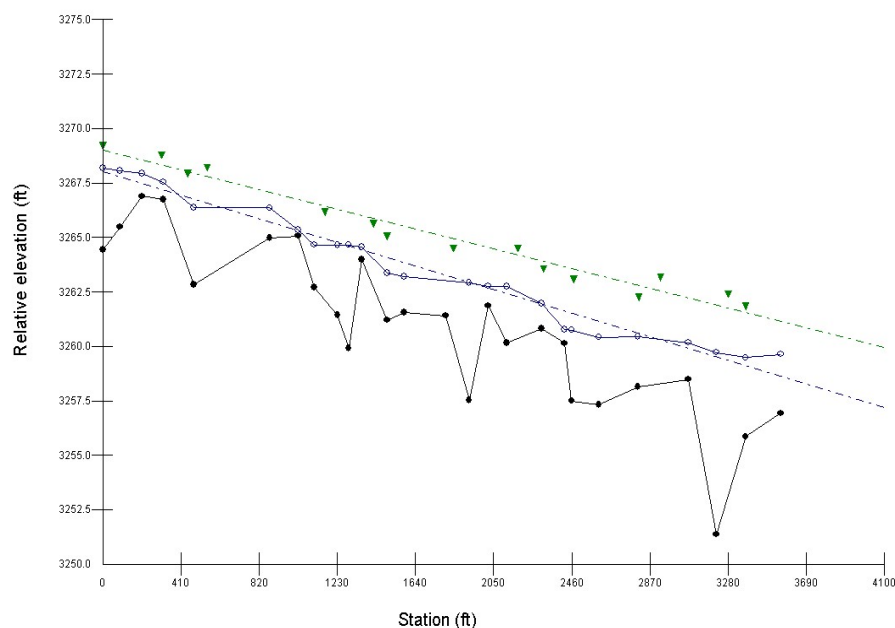
Habitat Type (n)	Bankfull width (ft)	Average depth (ft)	Width-to- depth ratio	Maximum depth (ft)	Cross-sectional area (ft <sup>2</sup> )
Riffle (3)	475 (400-529)	2.2 (1.8-2.4)	214 (204-220)	6.3 (5.0-8.6)	1,076 (729-1,291)



**Figure B-11.** Cross-section depicting the braided channel morphology in CFR3-C.

### B.3.6.3 Channel Profile

The channel profile survey included approximately 3,700 ft of CFR3-C. Figure B-12 presents the longitudinal profile graph depicting thalweg, water surface, and bankfull features. Best fit lines were applied to the water surface and bankfull data. As noted, the bedform was comprised of closely spaced riffle and pool sequences formed by converging flow lines and localized scour. Extensive mid-channel bars caused the flow to diverge at the apex of the deposits and converge with opposing flow lines, causing localized bed scour. Similar to CFR3-A, the bedforms were high unstable, with frequent shifts across the active belt width.



**Figure B-12.** Longitudinal channel profile graph depicting dominant bed morphology, water surface facet slopes, and bankfull features within CFR3-C. The green points represent the bankfull floodplain with a best-fit line, the blue points are the water surface with a best-fit line, and the black points represent the thalweg.

Longitudinal profile data are summarized in Table B-19 and B-20. Average water surface slope was 0.003 ft/ft. Riffle slope were steeper, averaging 0.007 or 2.3 times the average water surface slope. Stable pool features were not observed during the reach survey and were therefore excluded from the analysis.

**Table B-19.** Summary of longitudinal channel profile data (ft).

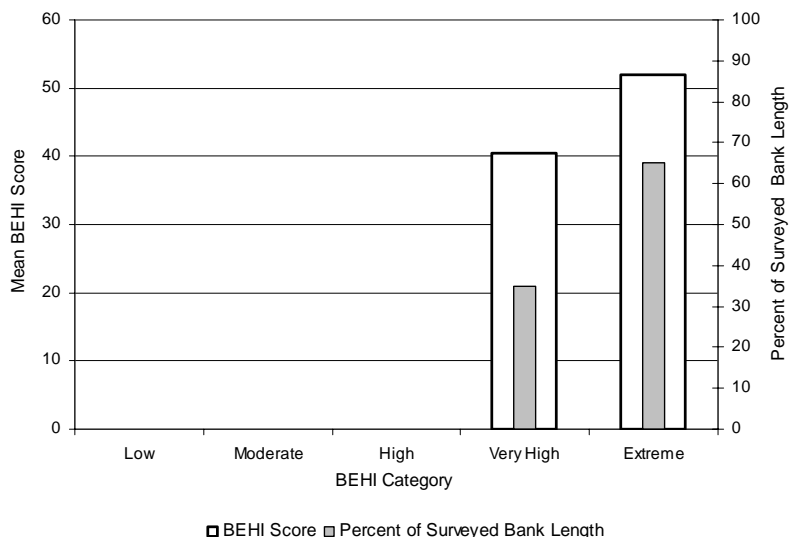
Valley Slope	Ave. Water Surface Slope	Riffle Slope	Pool Slope	Pool to Pool Spacing	Pool Length
0.003	0.003	0.007	n/a	n/a	n/a

**Table B-20.** Summary of channel longitudinal profile dimensionless ratios.

Riffle Slope / Ave. Slope	Pool Slope / Ave. Slope	Pool Length / Bankfull Width	Pool to Pool Spacing / Bankfull Width
2.33	n/a	n/a	n/a

#### B.3.6.4 Bank Integrity

The bank integrity analysis included an evaluation of four bank sites with a total surveyed bank length of approximately 1,700 ft within CFR3-C. Bank erosion potential ranged from very high (35%) to extreme (65%). Numeric BEHI ratings ranged from 40.5 at Site 3 to 53.2 and Site 2. Figure B-13 summarizes the results for CFR3-C.



**Figure B-13.** BEHI scores and ratings for representative bank condition sites in CFR3-C.

Bank height ratios ranged from 1.4 to 2.3. Root depth ratios ranged from 0.1 to 0.4 with a mean of 0.2. Weighted root density included values of approximately 2.0, 2.1, 4.4 and 12. Bank angles ranged from 75 to 90 degrees and surface protection from 10 to 25 percent. Bank material composition at sites 1 and 2 was primarily sand with no stratification. Bank composition at Site 3 consisted of gravel with a high fraction of sand and unstable strata. There was significant difference in bank material composition between the upper reaches of CFR3 and CFR3-C. Fine-grained sediments comprising the bank profiles in the lower segments of the reach likely reflect deposition that occurred during the 1908 flood and during subsequent higher magnitude events. The finer grained deposits also reflect the flattening of the valley slope and decreased sediment transport capacity of the reach.

### B.3.6.5 Bed Resistance and Channel Hydraulics

CFR3-C was characterized by coarse gravel substrate, with particles ranging in size from 1.0 mm (very coarse sand) to a maximum particle size of 180 mm (large cobble). Hydraulic modeling and incipient motion results for a typical cross-section in Reach CFR3-C are presented in Table B-21.

**Table B-21.** Hydraulic and incipient motion modeling results for bankfull discharge.

Velocity (f/s)	Manning's n-value	Total shear stress (lbs/ft <sup>2</sup> )	Grain Diameter (mm)	Size Class (% finer than)
4.6	0.030	0.41	80-90 <sup>1</sup>	D <sub>94</sub> - D <sub>96</sub>
			20-30 <sup>2</sup>	D <sub>52</sub> - D <sub>63</sub>

<sup>1</sup> Modified Shields curve (D. Rosgen, 2001)

<sup>2</sup> Shields curve

Comparing the results of the hydraulic modeling to the modified Shields curve and composite sediment gradation data for CFR3-C (Table B-22), the channel is capable of initiating motion of a 80-90 mm particle (D<sub>85</sub>-D<sub>90</sub> particle size class) during bankfull discharge. The results of the hydraulic modeling were also compared to the RSI results. The geometric mean of the largest

mobile particles sampled was 102 mm. When compared to the cumulative particle size distribution from the riffle sediment gradation curve, an RSI score of 98 was derived.

**Table B-22.** Particle size distribution and riffle stability index (RSI) results,

Composite Gradation (mm)						RSI	
D <sub>16</sub>	D <sub>35</sub>	D <sub>50</sub>	D <sub>84</sub>	D <sub>95</sub>	D <sub>100</sub>	Geometric Mean (mm)	Score
1	6	18	53	80	180	102	98

The combined results applying the modified Shields curve and RSI data indicate that the current channel regime is capable of initiating motion of particles ranging in size from 80 mm to 102 mm (small cobble), or the D<sub>94</sub>-D<sub>98</sub> size class of the available bed material during bankfull discharge. The standard Shields curve predicted a much small particle size class ranging from 20 mm to 30mm, or the D<sub>52</sub>-D<sub>63</sub> of the bed material. Based on the combined results of the modified Shields curve and RSI, the standard Shields curve like under-predicted grain size diameter for the modeled critical shear stress values.

### B.3.9 CFR1 - Bandmann Flats Existing Conditions

Downstream of Milltown Dam and the confluence with the BFR, the CFR valley narrows and becomes confined between glacial outwash terraces to the north and a bedrock valley wall to the south. From the Burlington North-Santa Fe (BNSF) railroad crossing and entering Bandmann Flats, valley morphology transitions to a Type IV valley (Rosgen, 1996), characterized by steep, adjacent hillslopes exuding a gorge-like appearance on the landscape. Valley floor gradients were minor and the planform pattern was entrenched and structurally influenced if not entirely controlled by the valley morphology. Riffle-pool bedforms characterized the bed profile and sediment supply was low. In this type of setting, entrenched F type channels typically predominate, but where floodplain development occurs, moderately entrenched Pool-Riffle (Montgomery and Buffington, 1993) or C stream type (Rosgen, 1996) channels can also evolve.

Located downstream of the CFR-BFR confluence, the Bandmann Flats reach experiences a much greater flow regime than CFR2 and CFR3. The bankfull discharge triples in magnitude relative to CFR2 and CFR3, with an estimated flow rate of 10,400 cfs. The morphology of the river likewise reflects this increase in stream order, with bankfull riffle channel widths increasing from an average of 183 ft in CFR3-B to 239 ft in Bandmann Flats.



**Figure B-14.** View of CFR1 at Bandmann Flats looking upstream towards the Interstate 90 bridge from Highway 200. The channel is confined to the north by a glacial outwash terrace and maintains a relatively narrow floodprone area.

### B.3.9.1 Planform

The planform analysis of Bandmann Flats extended from the Interstate 90 bridge downstream to the USGS streamflow gauging station located near East Missoula (Figure B-1). As indicated, valley constraints imposed on the channel limited floodplain development, resulting in a relatively entrenched F3<sub>1</sub> channel type (cobble dominated with bedrock influence), and low sinuous planform. Bankfull channel widths ranged from 224 ft to 257 ft with an average entrenchment ratio and sinuosity of 1.17. Existing planform channel dimensions are summarized in Table B-23.

**Table B-23.** The existing planform channel dimensions in CFR1 at Bandmann Flats. Mean Values (range)

Channel Type	Sinuosity	Bankfull Width (ft)	Entrenchment Ratio	Meander Belt Width (ft)	Meander Length (ft)	Radius of Curvature (ft)
F3 <sub>1</sub>	1.17	239 (224-257)	1.17	1,500 (n/a)	4,600 (n/a)	2,000

### B.3.9.2 Channel Cross-Sections

Ten cross-sections were surveyed along a 4,500 ft reach in Bandmann Flats to characterize riffle, pool, run and glide morphology. Bankfull riffle habitat unit widths ranged from 224 ft to 257 ft, with corresponding width-to-depth ratios ranging from 34 to 44, respectively. Maximum riffle depths ranged from 8.3 ft to 9.2 ft with an average value of 8.8 ft. Average bankfull cross-sectional area for riffle habitat units was 1,477 ft<sup>2</sup>, ranging from 1,304 ft<sup>2</sup> to 1,611 ft<sup>2</sup>. Table B-24 summarizes existing cross-section dimensions. A typical riffle channel cross-section is displayed in Figure B-15.

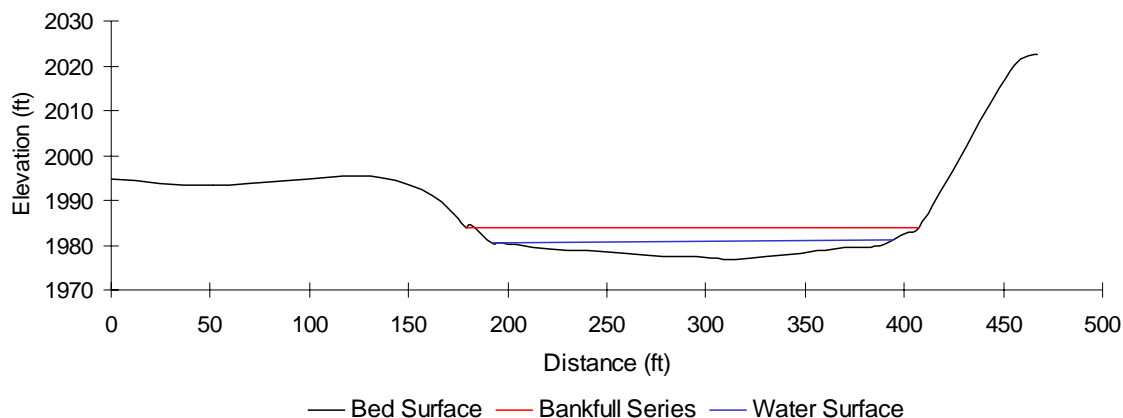
**Table B-24.** Existing cross-section dimensions in Bandmann Flats. Mean value (range).

Habitat Type (n)	Bankfull width (ft)	Average depth (ft)	Width-to-depth ratio	Maximum depth (ft)	Cross-sectional area (ft <sup>2</sup> )
Riffle (3)	239 (224-257)	6.2 (5.8-6.9)	39 (34-44)	8.8 (8.3-9.2)	1,477 (1,304-1,611)
Pool (2)	205 (177-234)	9.4 (7.2-11.1)	n/a	23.8 (23-24.7)	1,935 (1,272-2,598)
Run (2)	221 (217-224)	5.9 (5.8-6.0)	n/a	8.7 (8.3-9.1)	1,299 (1,293-1,304)
Glide (3)	272 (242-290)	5.8 (4.8-7.6)	n/a	8.6 (6.8-12.0)	1,558 (1,389-1,845)

Two pool cross-sections were surveyed in Bandmann Flats. The pools were associated with bedrock exposures along the channel margins and thalweg. Average bankfull widths of pool habitat units were generally narrower and deeper than riffle units, ranging from 177 ft to 234 ft, with maximum depths of 23.0 ft to 24.7 ft. Average bankfull cross-sectional area was 1,935 ft<sup>2</sup>, approximately 31% greater than riffle habitat units. Glide habitat units corresponded to pool tailouts and were generally wider and shallower than riffle, pool and run habitat units. Bankfull widths for glides ranged from 242 ft to 290 ft, with average depths ranging from 4.8 ft to 7.6 ft.



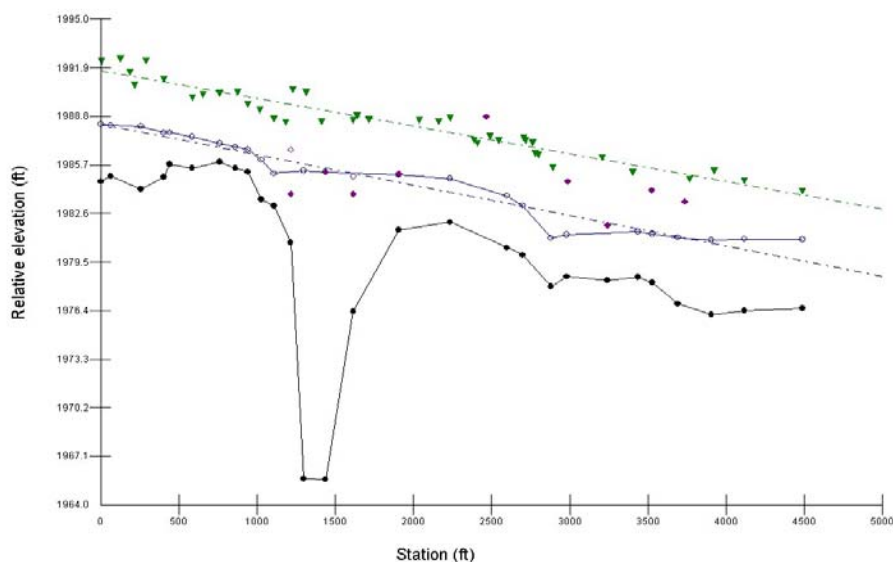
Runs were identified as areas where the profile transitioned from riffle to pool habitat units, and had the least cross-sectional area of all sampled habitat units (average of 1,299 ft<sup>2</sup>). Bankfull run widths ranged from 217 ft to 224 ft with mean depths of 5.8 ft to 6.0 ft.



**Figure B-15.** Typical riffle cross-section in CFR1 at Bandmann Flats.

### B.3.9.3 Channel Profile

The channel profile at Bandmann Flats included approximately 4,500 ft of channel (Figure B-16). The most prominent feature captured in the survey was a large scour pool measuring 24.7 ft in depth formed by a bedrock outcrop on the north side of the channel. The outcrop constricted the bankfull channel width causing rapid flow contraction and bed scour.



**Figure B-16.** Longitudinal channel profile graph depicting dominant bed morphology, water surface facet slopes, and bankfull features within CFR1 at Bandmann Flats. The green points represent the bankfull floodplain with a best-fit line, the blue points are the water surface with a best-fit line, and the black points represent the thalweg.

Longitudinal channel profile data are summarized in Table B-25 and B-26. Average water surface slope was 0.002 ft/ft. Average riffle and pool slopes were 0.003 ft/ft and 0.001 ft/ft respectively. Similar to CFR3-B, the riffle slopes were steeper by approximately 150% relative to the average water surface slope, and pools were flatter or approximately half of the average water surface slope.

**Table B-25.** Summary of longitudinal channel profile data (ft).

Valley Slope	Ave. Water Surface Slope	Riffle Slope	Pool Slope	Pool to Pool Spacing	Pool Length (ft)
0.002	0.002	0.003	0.001	4,087	403

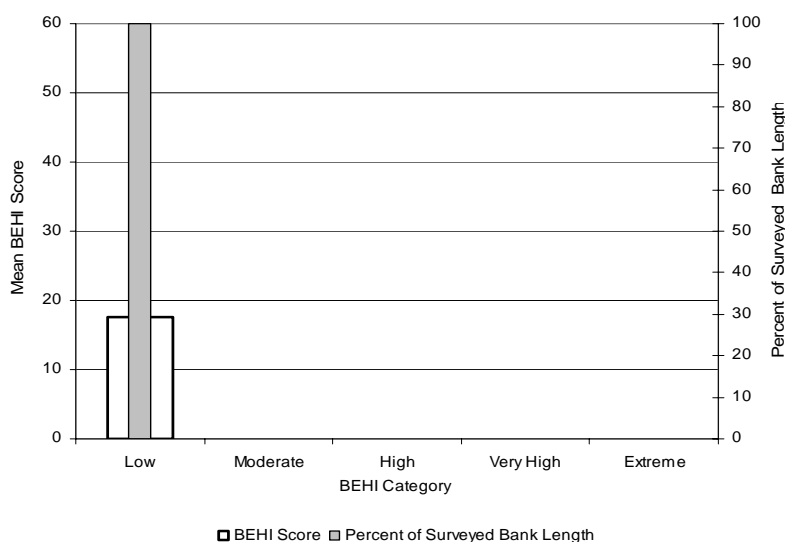
Pools within Bandmann Flats were associated with channel obstructions such as bedrock. Pool frequency averaged one pool every 17 bankfull channel widths, or 4,807 ft.

**Table B-26.** Summary of longitudinal channel profile dimensionless ratios.

Riffle Slope / Ave. Slope	Pool Slope / Ave. Slope	Pool Length / Bankfull Width	Pool to Pool Spacing / Bankfull Width
1.5	0.5	1.7	17.1

### B.3.9.4 Bank Integrity

The bank integrity analysis included an evaluation of four bank sites with a total surveyed bank length of approximately 2,900 ft within CFR at Bandmann Flats. Figure B-17 summarizes the results for CFR at Bandmann Flats. Bank erosion potential at all sampled sites was low. Numeric BEHI ratings included 19.2 at Site 1, 19.1 at Site 2, 15.8 at Site 3 and 16.4 at Site 4.



**Figure B-17.** BEHI scores and ratings for representative bank condition sites in CFR1 at Bandmann Flats.

Bank height ratios were 1.0 for all sampled sites and root depth ratios ranged from 0.1 to 0.3. Although entrenched, a defined floodplain bench was present along a majority of the reach and buffered high flows from the steeper, adjacent hillslopes. Terraces and hillslopes supported a conifer dominated climax community of the Ponderosa pine/red osier dogwood (*Pinus ponderosa*/*Cornus stolonifera*) habitat type. Active floodplains were willow dominated. Weighted root density included values of 6.7, 7.7, 9.5, and 11.3. Bank angles ranged from 45 to 60 degrees and surface protection from 55 to 75 percent. Bank material composition was primarily gravel with a high fraction of sand and no unstable strata.

### B.3.9.5 Bed Resistance and Channel Hydraulics

CFR1 at Bandmann Flats was characterized by coarse gravel substrate (with bedrock inclusions), with particles ranging in size from 11 mm (medium gravel) to a maximum particle size of 1,024 mm (medium boulder). Hydraulic modeling and incipient motion average results for two riffle cross-sections in Bandmann Flats are presented in Table B-27.

**Table B-27.** Hydraulic and incipient motion modeling results for bankfull discharge.

Velocity (f/s)	Manning's n-value	Total shear stress (lbs/ft <sup>2</sup> )	Grain Diameter (mm)	Size Class (% finer than)
6.61	0.035	0.79	115-125 <sup>1</sup> 45-55 <sup>2</sup>	D <sub>70</sub> -D <sub>75</sub> D <sub>40</sub> -D <sub>45</sub>

<sup>1</sup> Modified Shields curve (D. Rosgen, 2001)

<sup>2</sup> Shields curve

Comparing the results of the hydraulic modeling to the modified Shields curve and composite sediment gradation data (Table B-28), the channel is capable of initiating motion of a 115 mm to 125 mm particle (D<sub>70</sub>-D<sub>75</sub> particle size class) during bankfull discharge. The results of the hydraulic modeling were also compared to the RSI results. The geometric mean of the largest mobile particles sampled was 180 mm. When compared to the cumulative particle size distribution from the riffle sediment gradation curve, an RSI score of 87 was derived.

**Table B-28.** Particle size distribution and riffle stability index (RSI) results.

Composite Gradation (mm)						RSI	
D <sub>16</sub>	D <sub>35</sub>	D <sub>50</sub>	D <sub>84</sub>	D <sub>95</sub>	D <sub>100</sub>	Geometric Mean (mm)	Score
11	44	74	150	215	1,024	180	87

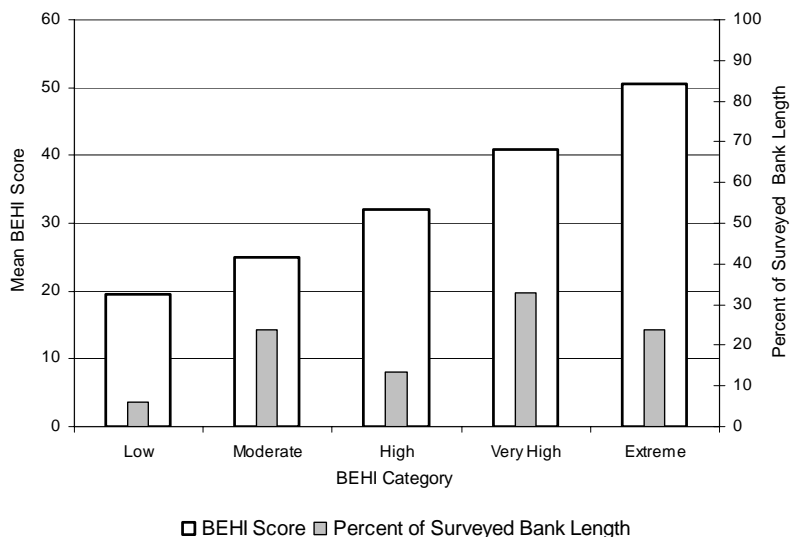
The combined results applying the modified Shields curve and RSI data indicate that the current channel regime is capable of initiating motion of particles ranging in size from 115 mm to 125mm (small cobble), or the D<sub>70</sub>-D<sub>75</sub> size class of the available bed material during bankfull discharge. The standard Shields curve predicted a much small particle size class ranging from 45mm to 55 mm, or the D<sub>40-45</sub> of the bed material. Based on the combined results of the modified Shields curve and RSI, the standard Shields curve like under-predicted grain size diameter for the modeled critical shear stress values.

### B.3.10 Discussion

Reaches CFR3-A and CFR3-C were characterized by braided, multiple channel regimes. Sediment sources associated with eroding streambanks and bed instabilities were frequent with streambank erodibility potential rating high to extreme. The increased availability of sediment and reduced sediment transport capacity have resulted in aggraded channel conditions. The aerial photo series indicated that this condition has persisted in these sub-reaches since 1937 and that the system was likely sensitized by anthropogenic impacts and natural events well before this time period.

CFR3-B represents a potential reference or “best possible” state for the CFR, considering past anthropogenic impacts and natural perturbations in the watershed. Conditions exemplified by the channel’s dimensions, pattern, and profile; the distribution and characteristics of sediment and sediment loading to the channel; and the riparian condition were the primary factors in designating CFR3-B as a potential reference reach. The reach exhibited a relatively narrow width-to-depth ratio, well-vegetated banks, moderate pool frequency, and substantial pool depths. Compared to the non-reference reaches which were characterized by higher width-to-depth ratios, less efficient sediment transport suggested by mid-channel bar development, and less frequent and less complex pools, CFR3-B was considered more stable and reflective of the potential channel morphology of CFR3.

In low gradient, unconfined reaches such as CFR3, loss of bank integrity can result in dramatic channel widening (Montgomery and Buffington, 1993). The effects of vegetation conversion within CFR3-A and CFR3-C, compounded by historical flood events and other impacts, are accelerating rates of bank erosion and lateral channel migration. In general, floodplain and streambank vegetation communities are of younger age classes and in many instances composed of noxious weed and agricultural types, offering minimal streambank stability compared to the historical vegetation communities that were characterized by forested riparian plant communities including non-climax cottonwood/ red osier dogwood interspersed with conifer dominated climax communities such as the Ponderosa pine/red osier dogwood (*Pinus ponderosa*/*Cornus stolonifera*) or Douglas fir/red osier dogwood (*Pseudotsuga menziesii*/*Cornus stolonifera*) habitat types (Hansen et al., 1995). Overall, bank erosion potential in CFR3 ranged from moderate to extreme. The distribution of conditions included low (6%), moderate (24%), high (13%), very high (33%) and extreme (24%) (Figure B-18). High to extreme ratings were associated with the braided channel regimes. Low to moderate ratings were found in the CFR3-B reference reach, where vegetation was more dominated by historical cover types providing increased bank integrity and resistance to erosion. The planform morphology and stability of the reaches likewise reflected the prevailing vegetation conditions and sediment regimes. CFR3-B, characterized by low to moderate sediment supply, maintained a meandering plan form with a defined dominant bankfull channel and active flood channels whereas CFR3-A and CFR3-AC were braided and unstable with frequent deposition of bars and high sediment supply.



**Figure B-18.** BEHI scores and ratings for all representative bank condition sites in CFR3.

Results of the incipient motion analysis seemed to support the conclusions drawn from the physical channel reach stability assessment. The results indicated varied sediment transport characteristics within CFR3, which are estimates at best due to the lack of bedload data and inherent limitations of the standard and modified Shields curves for estimating incipient motion in gravel bed rivers (for a more detailed analysis on sediment transport, refer to Appendix C). A general interpretation of the results is provided in the following paragraphs.

Segments of the CFR upstream and within CFR3-A are presently aligned against the historical railroad grade located on the south side of the floodplain. In these sections, the river is channelized with elevated stream power, a function of the relatively deep channel thalweg, steep energy grade line, and increased mean channel velocity relative to upstream and downstream reaches. Elevated stream power is likely increasing the rate of fine and coarse sediment transport to the downstream braided channel regime in CFR3-A. The sediment transport competency is lower in CFR3-A relative to the upstream channelized sections and downstream single-threaded sections of the CFR in CFR3-B. Results of the incipient motion analysis indicate that up to the  $D_{60}$ - $D_{65}$  (80 mm to 90 mm) of the bed material is at least mobilized during bankfull and greater discharges. The remaining size fractions, representing small cobble to small boulder size classes (90 mm to 256 mm) are deposited in the multiple channels.

Downstream in CFR3-B, the Clark Fork River transitioned to a meandering, single-thread channel type. Bankfull riffle widths ranged from 138 ft to 206 ft and width-to-depth ratios from 37 to 77. Results of the incipient motion analysis indicated that the reach initiated movement of particles ranging from 95 mm to 105 mm. The effect of lower width-to-depth ratios increases the transport competency of the reach relative to upstream and downstream braided regimes. The efficient transport characteristics are likewise reflected in the stable bedforms, moderately deep pools, and good bank stability.

As the CFR transitions to CFR3-C, the channel is again characterized by a braided, multiple thread regime. Valley slope is reduced from an average gradient of 0.0039 ft/ft in CFR3-A to

0.0030 ft/ft in CFR 3-C. The channel materials are significantly finer and the incipient motion results indicate decreased sediment transport competency, similar to CFR3-A.

In summary, the primary factors maintaining braided channel conditions within CFR3-A and CFR3-C included 1) abundant bedload supply; 2) high bank erodability reflecting the unstable channel conditions and altered riparian floristics; 3) historical flooding and variable discharge; and 4) backwater effects induced by Milltown Dam and potentially the Duck Bridge. Based on review of all available data and information, it is likely that CFR3 was pre-disposed to braiding prior to 1937 and was particularly affected by the 1908 flood of record. Backwater effects imposed by Milltown Dam extended upstream to the lower end of CFR3-B. These effects resulted in decreased sediment transport capacity, sediment deposition, and accelerated lateral migration.

Given these current conditions, the tendency for recovery of the braided regimes to a more stable planform is unlikely in a reasonable time frame especially with periodic flood events that increase sediment loading to the channel via upstream delivery and local bank failures. Further analysis on the existing and proposed sediment transport characteristics of CFR3, CFR2, and CFR1 are presented in Appendix C and will be refined during the final design phase.

Similar to CFR3-B, Bandmann Flats in CFR1 represented a relatively stable and functioning reach of the Clark Fork River. Developed within a relatively confined valley type, the channel displayed a low entrenchment ratio relative to the upstream alluvial reaches and a stable channel profile characterized by riffle-pool bedforms. The active floodplains and streambanks were well-vegetated and displayed low bank erodability ratings. Sediment supply was considered low and the channel displayed efficient transport capacity.

## **B.4 BFR EXISTING CONDITIONS**

### **B.4.1 Introduction**

This section presents the results of two channel reach assessments conducted on the Blackfoot River (BFR). The first assessment was complete near Ovando and included 2.75 miles of the main stem BFR. The assessment quantitatively described the geomorphic character of a system transitioning from an unconfined, alluvial valley to a confined, structurally controlled type. Dimensionless ratios for pattern, cross-section and profile characteristics were developed to supplement design validation of the CFR within CFR3, CFR2, and CFR1. Similar to the BFR at the Ovando study site, the CFR will be designed to transition from the unconfined CFR3 alluvial valley upstream of Duck Bridge, to a semi-confined type in CFR2 (Milltown Reservoir), and ultimately to a confined type in CFR1 downstream of Milltown Dam. Three contiguous channel reaches were delineated in the study area. The upstream most segment Reach 1, included 8,500 ft of unconfined C4 or Riffle-Pool channel type. Reach 2 was characterized as a moderately confined and entrenched B4c channel type and encompassed 2,300 ft of river and floodplain. Reach 3 encompassed the lower 2,900 ft of the reach and classified as an entrenched F4 channel type. The survey produced 33 cross-sections and a 13,700 ft continuous longitudinal profile of the BFR. Sixteen cross-sections were surveyed in Reach 1, nine in Reach 2, and eight cross-sections in Reach 3. Ten of the 33 cross-sections encompassed the entire width of the BFR



valley. Additional reach metrics as detailed in Section 2.0 of this report were also collected, including bank stability and hydraulic and sediment transport analyses. Figure B-1 provides a general vicinity map of the reaches near Ovando.

The second reach assessment was completed northeast of Bonner at the USGS streamflow gaging station on the BFR. The assessment characterized the planform, cross-sectional, and bed profile morphology of an entrenched B stream type. The assessment results are intended to refine and validate channel and floodplain design dimensions for the lower BFR upstream of the confluence with the CFR and Milltown Dam. The survey included five cross-sections and a 2,800 ft longitudinal profile. Bank stability and sediment data were also collected.

#### B.4.2. General Hydrology

The BFR sub-watershed has relatively high mean annual precipitation, ranging from 16 inches at the confluence with the CFR to 60 inches at the watershed divide (USDA Soil Conservation Service, 1990). A majority of the precipitation occurs as snow that typically melts between April and June producing snowmelt runoff dominated hydrographs. The annual hydrograph generally exhibits one peak flow period that occurs in May or June in response to snowmelt runoff. Snow pack characteristics, air temperature, and periodic rain events influence the timing and duration of spring runoff.

Based on data available for the periods of record, the BFR typically flows less than 600 cfs from September through March with baseflows (discharge less than 600 cfs) occurring from January through early March. Discharge typically exceeds 5,000 cfs from late May through mid-June with peak flows occurring in early June.

A detailed hydrology and flood series analysis of the BFR was prepared by WWC and RDG in cooperation with the USGS and EMC<sup>2</sup> (Appendix A). Flood magnitudes for selected recurrence intervals were determined from a flood frequency curve using the log-Pearson Type III distribution method as outlined in Bulletin #17B Guidelines for Determining Flood Flow Frequency (U.S. Water Resources Council, 1982). Analysis of flood frequency using historical streamflow gaging records, and field calibration of bankfull discharge at the USGS gaging stations were used to determine bankfull discharge at the USGS gaging station near Bonner.

The selected bankfull and flood magnitudes for selected recurrence intervals are presented in Table B-29.

**Table B-29.** Selected bankfull ( $Q_{bf}$ ) and flood flow values (cfs) for the BFR near Bonner.  
 Values were rounded to the nearest 100 cfs.

USGS Station	Recurrence Interval (yrs)						
	$Q_{bf}$	$Q_2$	$Q_{10}$	$Q_{25}$	$Q_{50}$	$Q_{100}$	$Q_{500}$
BFR near Bonner	6,200	8,670	14,600	17,300	19,200	21,000	24,900

A more detailed discussion on the flood series hydrology of the BFR near Bonner is included in Appendix A.

### B.4.3 BFR at Ovando Reach 1 Existing Conditions

#### B.4.3.1 Planform

The planform morphology of Reach 1 was characterized as a meandering, single thread channel type and classified as Riffle-Pool channel type (Montgomery and Buffington, 1993) and a C4 stream type (Rosgen, 1996). The general form of the channel has remained relatively stable over time (R. Pierce, Montana Fish, Wildlife & Parks, personal communication) and was considered to be in balance with the prevailing streamflow and sediment regimes of the watershed. Changes in planform were detected in the aerial photo series, however, the channel dimensions have remained consistent over time and within the natural range of variability expected for this channel type. There was one abandoned remnant of a bridge in the middle of the upstream C4 reach, this structure has changed some of the planform geometry and instigated bank erosion. In locations where the adjacent hillslopes encroached on the channel, eroding banks were common. Elevated loading of unconsolidated glacio-fluvial and lacustrine sediments to the reach was noted and associated with bank erosion and shallow seated slope failures into the active channel. In these locations, a coarse cobble toe was formed at the base of the bank and terrace features, providing surface protection to the lower one-third of the bank profile. The reach displayed a slightly higher meander belt width relative to the CFR3 alluvial valley type, with an average width of 790 ft (Table B-30). Meander length averaged 1,708 ft, with a range of 905 ft to 2,585 ft. Radius of curvature ranged from 148 ft to 687 ft, with an average of 437 ft.

**Table B-30.** Existing planform channel dimensions in Reach 1 of the BFR near Ovando.  
 Mean values (range).

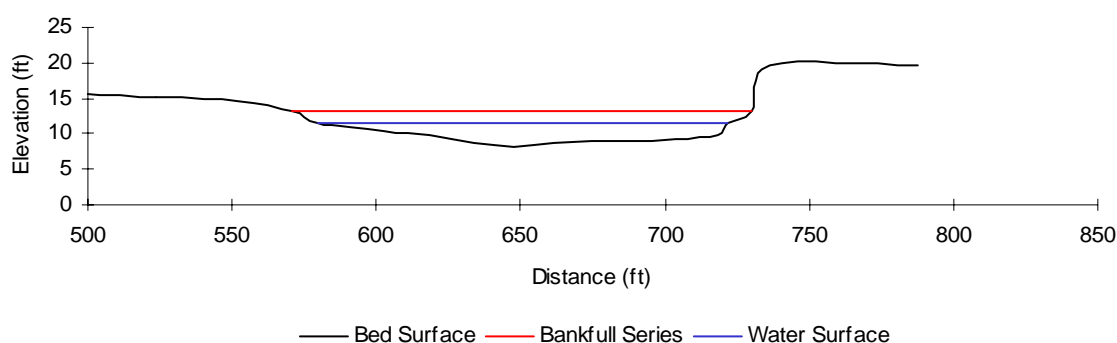
Channel Type	Sinuosity	Bankfull Width (ft)	Entrenchment Ratio	Meander Belt Width (ft)	Meander Length (ft)	Radius of Curvature (ft)
C4	1.3	168 (154-184)	1.29	790 (490-1285)	1,708 (905-2,585)	437 (148-687)

#### B.4.3.2 Channel Cross-Sections

A total of fourteen cross-sections were surveyed in Reach 1. Three cross-sections were surveyed in riffle and run habitat units and four in pool and glide units. Bankfull riffle habitat unit widths ranged from 154 ft to 184 ft, with corresponding width-to-depth ratios ranging from 44-64, respectively (Table B-31). Maximum riffle depths ranged from 3.9 ft to 5.0 ft with an average value of 4.6 ft. Average bankfull cross-sectional area for riffle habitat units was 541 ft<sup>2</sup>, ranging from 529 ft<sup>2</sup> to 552 ft<sup>2</sup>.

**Table B-31.** Existing cross-section dimensions in Reach 1 of the BFR near Ovando. Average value (range).

Habitat Type (n)	Bankfull width (ft)	Average depth (ft)	Width-to-depth ratio	Maximum depth (ft)	Cross-sectional area (ft <sup>2</sup> )
Riffle (3)	168 (154-184)	3.2 (2.9-3.5)	53 (44-64)	4.6 (3.9-5.0)	541 (529-552)
Pool (4)	140 (122-151)	3.7 (3.5-3.9)	n/a	7.8 (6.3-10.8)	518 (429-584)
Run (3)	155 (134-173)	3.6 (3.0-4.6)	n/a	6.7 (6.2-6.9)	554 (465-616)
Glide (4)	196 (123-283)	3.1 (2.7-3.8)	n/a	5.0 (4.0-6.6)	580 (466-759)

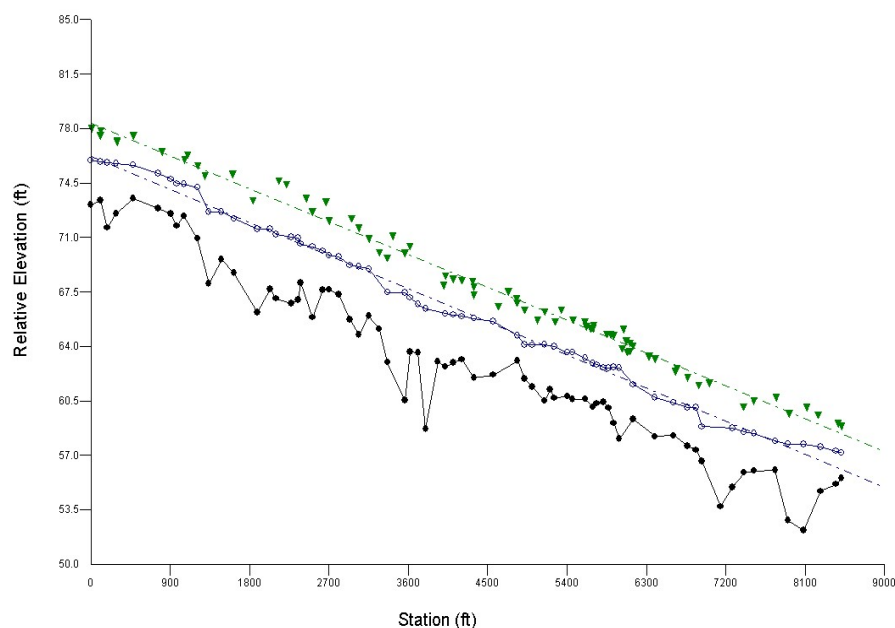


**Figure B-19.** Typical riffle cross-section in Reach 1.

Pool habitat units were generally deeper than riffle units, as expected. Bankfull pool width ranged from 122 ft to 151 ft with maximum depths of 6.3 ft to 10.8 ft. Average bankfull cross-sectional area was 518 ft<sup>2</sup>. Glide habitat units corresponded to pool tailouts and were generally wider and shallower than riffle, pool and run habitat units. Bankfull widths for glides ranged from 123 ft to 283 ft, with average depths ranging from 2.7 ft to 3.8 ft. Runs were identified as areas where the profile transitions from riffle to pool habitat units. Average run cross-sectional area was 554 ft<sup>2</sup>. Bankfull run widths ranged from 134 ft to 173 ft with mean depths of 3.0 ft to 4.6 ft.

#### B.4.3.3 Channel Profile

Longitudinal profile data were collected on a 8,500 ft representative segment of Reach 1. Features including channel thalweg, water surface, and bankfull floodplains were surveyed to characterize the channel profile. Bedform morphology was characterized by an undulating thalweg transitioning between pool and riffle sequences. Pools were formed primarily by flow through meander bends and lateral scour. Figure B-32 presents the longitudinal profile graph.



**Figure B-20.** Longitudinal channel profile graph depicting dominant bed morphology, water surface facet slopes, and bankfull features within Reach 1. The green points represent the bankfull floodplain with a best-fit line, the blue points are the water surface with a best-fit line, and the black points represent the thalweg.

Large woody debris aggregates were common along meander bends, however the relatively low meander radii also facilitated scour with high near-bank shear stress. Longitudinal channel profile data are summarized in Table B-32 and B-33. Average water surface slope was 0.0024 ft/ft. Average riffle and pool slopes were 0.0036 ft/ft and 0.0009 ft/ft respectively. Riffle slopes were steeper than the average water surface slope by approximately 150%. Pools were flatter or approximately 40% of the average water surface slope. On average, pools were 328 ft long with a spacing of 538 ft. This equated to a pool to pool spacing to bankfull width ratio of 3.2.

**Table B-32.** Summary of longitudinal channel profile data (ft).

Valley Slope	Ave. Water Surface Slope	Ave. Riffle Slope	Ave. Pool Slope	Pool to Pool Spacing (ft)	Pool Length (ft)
0.003	0.0024	0.0036	0.0009	538	328

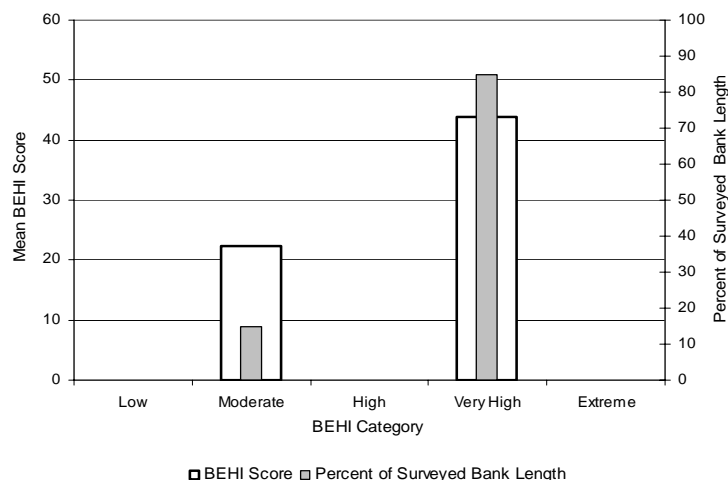
The ratios of riffle and pool slopes to average slope were 1.53 and 0.38, respectively. The dimensionless ratios reflect the natural transition between steeper riffle slopes to flat pool slopes.

**Table B-33.** Summary of longitudinal channel profile dimensionless ratios.

Riffle Slope / Ave. Slope	Pool Slope / Ave. Slope	Pool Length / Bankfull Width	Pool to Pool Spacing / Bankfull Width
1.53	0.38	1.93	3.2

#### B.4.3.4 Bank Integrity

The bank integrity analysis included an evaluation of four bank sites with total surveyed bank length of approximately 2,085 feet within Reach 1 (Figure B-21). Bank height ratios ranged from 1.4 to 2.0, with the exception of Site 2 with a bank height ratio of 4.7. Root depth ratios ranged from 0.1 to 0.4. Weighted root density included values of 0.4, 1.0, 5, and 28.9. Bank angles generally ranged from 80 to 90 degrees; bank angle at Site 1 was 60 degrees. Typical surface protection was 50 to 70 percent; surface protection at Site 1 was 10 percent.



**Figure B-21.** BEHI scores and ratings for representative bank condition sites in Reach 1.

Bank material composition was primarily gravel with a high fraction of sand and unstable strata. Figure B-22 includes photos of a representative streambank conditions in Reach 1.



**Figure B-22.** Typical streambank condition in Reach 1 of the BFR near Ovando study area. This site rated moderate in terms of bank erodability potential.

Bank erosion potential was either moderate or very high. Numeric BEHI ratings included 44.5 at Site 1, 45.7 at Site 2, 22.3 at Site 3, and 41.2 at Site 4. Fifteen percent (15%) of the surveyed bank rated moderate in terms of bank erosion potential, while the remaining 85% rated very high.

### B.4.3.5 Bed Resistance and Channel Hydraulics

Reach 1 was characterized by very coarse gravel substrate, with particles ranging in size from 8 mm (fine gravel) to a maximum particle size of 362 mm (small boulder). Hydraulic modeling and incipient motion average results for two typical riffle cross-section in Reach 1 are presented in Table B-34.

**Table B-34.** Hydraulic and incipient motion modeling results for bankfull discharge.

Velocity (f/s)	Manning's n-value	Total shear stress (lbs/ft <sup>2</sup> )	Grain Diameter (mm)	Size Class (% finer than)
4.94	0.031	0.52	90-95 <sup>1</sup> 30-35 <sup>2</sup>	D <sub>75</sub> - D <sub>80</sub> D <sub>32</sub> - D <sub>35</sub>

<sup>1</sup> Modified Shields curve (D. Rosgen, 2001)

<sup>2</sup> Shields curve

Comparing the results of the hydraulic modeling to the modified Shields curve and composite sediment gradation data (Table B-35), the channel is capable of initiating motion of a 90-95 mm particle (D<sub>75</sub>- D<sub>80</sub> particle size class) during bankfull discharge. The results of the hydraulic modeling were also compared to the RSI results presented in Table B-35. The geometric mean of the largest mobile particles sampled was 145 mm. When compared to the cumulative particle size distribution from the riffle sediment gradation curve, an RSI score of 90 was derived.

**Table B-35.** Particle Size Distribution and Riffle Stability Index (RSI) Results.

Composite Gradation (mm)						RSI	
D <sub>16</sub>	D <sub>35</sub>	D <sub>50</sub>	D <sub>84</sub>	D <sub>95</sub>	D <sub>100</sub>	Geometric Mean (mm)	Score
8	32	51	108	158	362	145	90

A third data set was also included in the analysis. Sieve analysis results from a depositional bar sample were tallied and the two largest particles averaged. Results indicated an average largest size particle of 132 mm, which was higher than the predicted particle size range from the modified Shields curve.

The combined results applying the modified Shields curve and RSI and bar sample data indicate that the current channel regime is capable of initiating motion of particles ranging in size from 95 mm to 145 mm, or the D<sub>75</sub>-D<sub>90</sub> size class of the available bed material during bankfull discharge. The standard Shields curve predicted a much small particle size class ranging from 30-35 mm, or the D<sub>32</sub>-D<sub>35</sub> of the bed material. Based on the combined results of the other methods, the standard Shields curve like under-predicted grain size diameter for the modeled critical shear stress values.

## B.4.4 BFR at Ovando Reach 2 Existing Conditions

### B.4.4.1 Planform

The BFR transitioned from a relatively unconfined channel type in Reach 1 to a moderately confined, cobble dominated B3 channel type in Reach 2. These channel types are moderately



entrenched systems developed within structurally controlled drainages. Meander belt width averaged 391 ft with a range of 265 to 516 ft. Meander length averaged 1,747 ft (range 1,616 – 1,877 ft). Radius of curvature ranged from 1,805 ft to 2,066 ft with a mean value of 1,935 ft. Table B-36 summarizes the existing planform dimensions of Reach 2.

**Table B-36.** Existing planform channel dimensions in Reach 2 of the BFR near Ovando.  
 Mean values (range).

Channel Type	Sinuosity	Bankfull Width (ft)	Entrenchment Ratio	Meander Belt Width (ft)	Meander Length (ft)	Radius of Curvature (ft)
B3	1.16	191 (178-217)	1.20 (1.05-1.40)	391 (265-516)	1,747 (1616-1877)	1,935 (1,805-2,066)

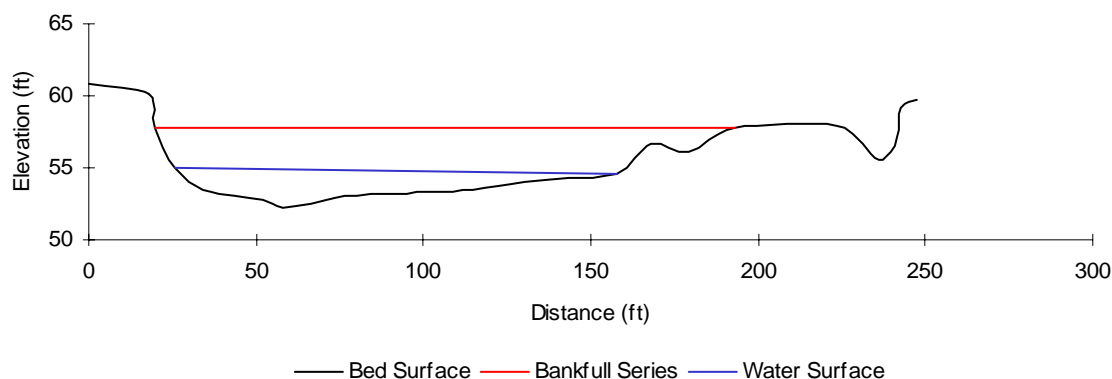
#### B.4.4.2 Channel Cross-Sections

Nine channel cross-sections were surveyed in Reach 2. Four cross-sections were surveyed in riffle units and two in run and glide units. Due to the relatively short reach length, only one pool was observed. Bankfull riffle habitat unit widths ranged from 178 ft to 217 ft, with corresponding width-to-depth ratios ranging from 38-73, respectively. Maximum riffle depths ranged from 3.8 ft to 5.6 ft with an average value of 4.7 ft. Average bankfull cross-sectional area for riffle habitat units was 575 ft<sup>2</sup>, ranging from 498 ft<sup>2</sup> to 655 ft<sup>2</sup>. Table B-37 summarizes the data. Figure B-23 depicts a typical riffle cross-section.

**Table B-37.** Existing cross-section dimensions in Reach 2 of the BFR near Ovando.  
 Average value (range)

Habitat Type (n)	Bankfull width (ft)	Average depth (ft)	Width-to-depth ratio	Maximum depth (ft)	Cross-sectional area (ft <sup>2</sup> )
Riffle (4)	191 (178-217)	3.0 (2.8-3.5)	56 (38-73)	4.7 (3.8-5.6)	575 (498-655)
Pool (1)	177	3.6	n/a	7.9	633
Run (2)	157 (152-161)	3.9 (3.4-4.3)	n/a	5.3 (4.3-6.3)	600 (548-653)
Glide (2)	148 (143-153)	3.7 (3.6-3.7)	n/a	5.8 (5.2-6.4)	540 (533-547)

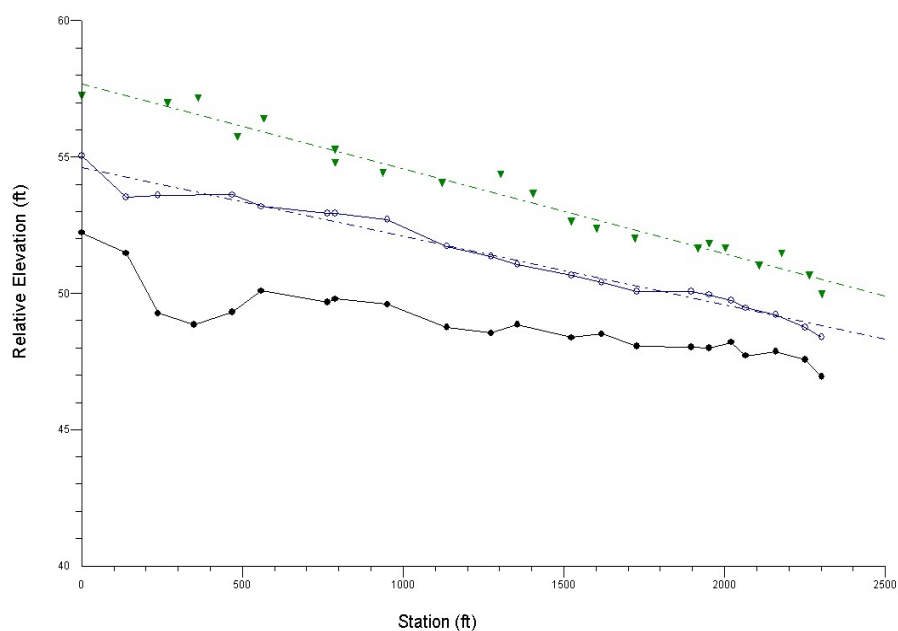
Bankfull pool width was 177 ft with a maximum depth of 7.9 ft. Pool bankfull cross-sectional area was 633 ft<sup>2</sup>. Bankfull glide widths ranged from 143 ft to 153 ft, with average depths ranging from 3.6 ft to 3.7 ft. Runs were identified as areas where the profile transitions from riffle to pool habitat units. Average run cross-sectional area was 600 ft<sup>2</sup>. Bankfull run widths ranged from 152 ft to 161 feet with mean depths of 3.4 ft to 4.3 ft.



**Figure B-23.** Typical riffle cross-section in Reach 2 of the BFR near Ovando.

#### B.4.4.3 Channel Profile

Longitudinal profile data were collected on a 2,300 ft representative segment of Reach 2. Features including channel thalweg, water surface, and bankfull floodplains were surveyed to characterize the channel profile. Bedform morphology was characterized by riffles and irregularly spaced scour pools associated with large cobble and boulder lag deposits. Figure B-24 presents the longitudinal profile graph. As noted, the profile was fairly homogenous with a majority of the habitat composed of riffle and run morphology.



**Figure B-24.** Longitudinal channel profile graph depicting dominant bed morphology, water surface facet slopes, and bankfull features within Reach 2. The green points represent the bankfull floodplain with a best-fit line, the blue points are the water surface with a best-fit line, and the black points represent the thalweg.

Longitudinal channel profile data are summarized in Table B-38 and B-39. Average water surface slope was 0.0025 ft/ft. Average riffle and pool slopes were 0.0053 ft/ft and 0.0008 ft/ft respectively. Riffle slopes were over-steepened by approximately 210% relative to the average water surface slope, and pools were flatter or approximately 30% of the average water surface slope. The ratios of riffle and pool slopes to average slope were 2.12 and 0.32, respectively.



**Figure B-25.** Pool habitat within Reach 2 was primarily formed and maintained by large cobble and boulder lag deposits resulting from continental glaciation.

**Table B-38.** Summary of longitudinal channel profile data (ft).

Valley Slope	Ave. Water Surface Slope	Ave. Riffle Slope	Ave. Pool Slope	Pool to Pool Spacing	Pool Length (ft)
0.003	0.0025	0.0053	0.0008	2,068	234

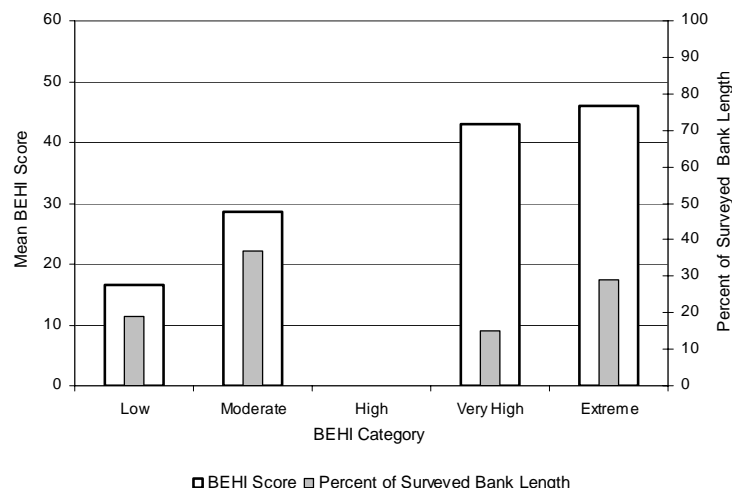
The primary pool formative structure in the B reach was large cobble and boulder lag deposits resulting from continental glaciation. The inventoried pool was 234 ft long. This equated to a pool to pool spacing to bankfull width ratio of 10.8, significantly lower than Reach 1.

**Table B-39.** Summary of longitudinal channel profile dimensionless ratios.

Riffle Slope / Ave. Slope	Pool Slope / Ave. Slope	Pool Length / Bankfull Width	Pool to Pool Spacing / Bankfull Width
2.12	0.32	1.23	10.8

#### B.4.4.4 Bank Integrity

The bank integrity analysis included an evaluation of four bank sites with a total surveyed bank length of approximately 2,330 feet within Reach 2. Figure B-26 summarizes the results. Bank erosion potential ranged from low to extreme. Numeric BEHI ratings included 28.7 at Site 1, 46.1 at Site 2, 43.1 at Site 3, and 16.6 at Site 4. Nineteen percent (19%) of the surveyed banks rated low in terms of bank erosion potential, 36% rated moderate, 15% very high and 29% extreme.



**Figure B-26.** BEHI scores and ratings for representative bank condition sites in Reach 2.

A majority of the significant sediment sources were associated with areas along the reach where the hillslopes were in direct contact with the channel. At these sites, sediment sources were comprised of unconsolidated glacial till and lacustrine sands and silts. Bank height ratios ranged from 1.7 to 6.3. Root depth ratios ranged from 0.01 to 0.5. Weighted root density included values of 0.5, 1.3, 28.1, and 32. Bank angles ranged from 35 to 60 degrees. Surface protection values ranges widely, including 65, 20, 30, and 80%. Bank material composition was primarily gravel with a high fraction of sand; bank Site 4 was mostly cobble with sand. No unstable strata were identified.

#### B.4.4.5 Bed Resistance and Channel Hydraulics

Reach 2 was characterized by very coarse gravel substrate, with particles ranging in size from 18 mm (coarse gravel) to a maximum particle size of 512 mm (small boulder). Hydraulic modeling and incipient motion average results for two typical riffle cross-sections in Reach 2 are presented in Table B-40.

<b>Table B-40.</b> Hydraulic and incipient motion modeling results for bankfull discharge.				
Velocity (f/s)	Manning's n-value	Total shear stress (lbs/ft <sup>2</sup> )	Grain Diameter (mm)	Size Class (% finer than)
4.58	0.036	0.64	95-105 <sup>1</sup>	D <sub>62</sub> -D <sub>67</sub>
			35-45 <sup>2</sup>	D <sub>28</sub> -D <sub>35</sub>

<sup>1</sup> Modified Shields curve (D. Rosgen, 2001)

<sup>2</sup> Shields curve

Comparing the results of the hydraulic modeling to the modified Shields curve and composite sediment gradation data, the channel is capable of initiating motion of a 90 mm to 105 mm particle (D<sub>62-67</sub>) during bankfull discharge. Due to the lack of depositional features, an RSI was not completed in Reach 2.

**Table B-41.** Particle size distributions in Reach 2.

Composite Gradation (mm)					
D <sub>16</sub>	D <sub>35</sub>	D <sub>50</sub>	D <sub>84</sub>	D <sub>95</sub>	D <sub>100</sub>
18	42	63	165	247	512

The results of the modified Shields curve indicate that the current channel regime is capable of initiating motion of particles ranging in size from 95 mm to 105 mm, or the D<sub>62</sub>-D<sub>67</sub> size class of the available bed material during bankfull discharge. The standard Shields curve predicted a much small particle size class ranging from 35 mm to 45 mm, or the D<sub>28</sub>-D<sub>35</sub> of the bed material.

#### B.4.5 BFR at Ovando Reach 3 Existing Conditions

The BFR progressed downstream into an incised alluvial valley. Similar to the Bandmann Flats section of CFR1, valley morphology was of the Type IV form (Rosgen, 1996), characterized by steep, adjacent hillslopes. Valley floor gradients were minor and the planform pattern was entrenched and structurally influenced if not entirely controlled by the valley morphology. Riffle-pool bedforms characterized the bed profile and sediment supply was low due to the presence of bedrock and dense riparian vegetation. The channel classified as an F4 type (Rosgen, 1996).

##### B.4.5.1 Planform

Results of the planform analysis are presented in Table B-42. Bankfull channel width average 183 ft with a mean entrenchment ratio of 1.23. Meander belt width, meander length, and radius of curvature average 524 ft, 2,054 ft, and 679 ft, respectively.

**Table B-42.** Existing planform channel Dimensions in Reach 3 of the BFR near Ovando.  
 Mean values (range).

Channel Type	Sinuosity	Bankfull Width (ft)	Entrenchment Ratio	Meander Belt Width (ft)	Meander Length (ft)	Radius of Curvature (ft)
F4	1.14	183 (173-194)	1.23 (1.20-1.26)	524 (516-530)	2,054 (1550-2530)	679 (468-875)

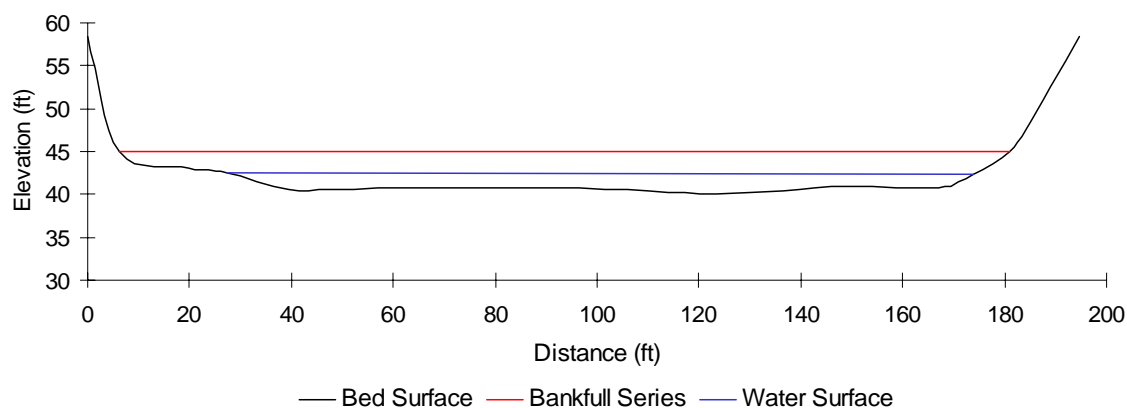
##### B.4.5.2 Channel Cross-Sections

Nine cross-sections were surveyed over a 3,000 ft section of Reach 3. Bankfull riffle habitat unit widths ranged from 173 ft to 194 ft, with corresponding width-to-depth ratios ranging from 44-82, respectively. Maximum riffle depths ranged from 4.0 ft to 5.7 ft with an average value of 4.8 ft. Average bankfull cross-sectional area for riffle habitat units was 550 ft<sup>2</sup>, ranging from 496 ft<sup>2</sup> to 604 ft<sup>2</sup>. Cross-section data is summarized in Table B-43.

**Table B-43.** Existing cross-section dimensions in Reach 3. Average value (range).

Habitat Type (n)	Bankfull width (ft)	Average depth (ft)	Width-to- depth ratio	Maximum depth (ft)	Cross-sectional area (ft <sup>2</sup> )
Riffle (4)	183 (173-194)	3.0 (2.6-3.5)	62 (44-82)	4.8 (4.0-5.7)	550 (496-604)
Pool (2)	174 (164-184)	4.1 (4.0-4.3)	n/a	6.9 (6.4-7.3)	712 (695-729)
Run (1)	175	3.8	n/a	5.0	663
Glide (2)	215 (179-252)	3.6 (3.1-4.1)	n/a	5.9 (4.8-6.9)	752 (728-777)

Two pool cross-sections were surveyed. Average bankfull widths of pool habitat units were generally narrower than riffle units and associated with valley and channel constrictions. Bankfull pool width ranged from 164 ft to 184 ft with maximum depths of 6.4 ft to 7.3 ft. Average bankfull cross-sectional area was 712 ft<sup>2</sup>, approximately 30% greater than riffle habitat units. Bankfull widths for glides were the widest feature and ranged in width from 179 ft to 252 ft. One run was identified in the survey. A typical cross-section is displayed in Figure B-27.

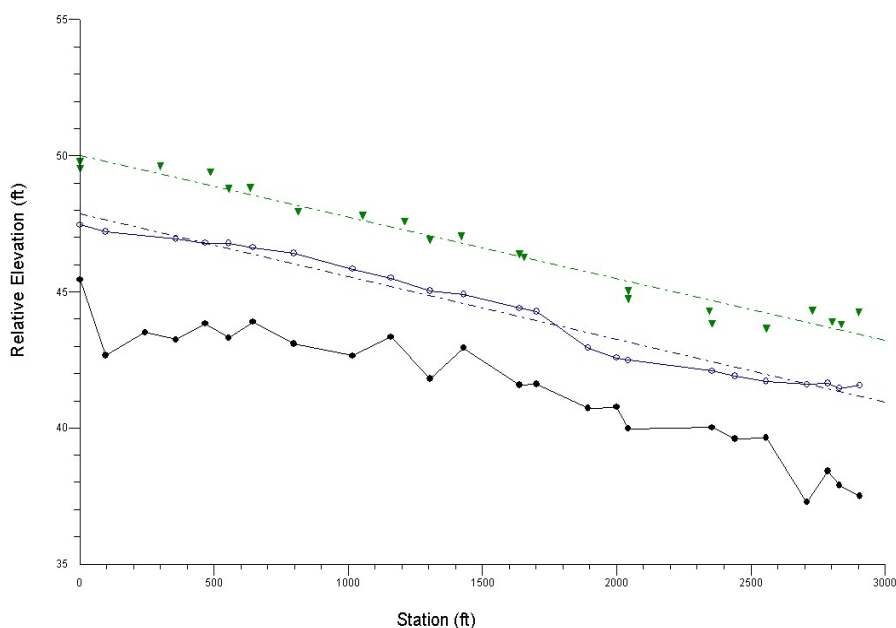


**Figure B-27.** Typical riffle cross-section in Reach 3.

#### B.4.5.2 Channel Profile

The longitudinal profile for Reach 3 is depicted in Figure B-28 and included approximately 2,900 ft of channel. Similar to Reach 2, the F4 channel type was comprised of irregularly spaced riffle and pool sequence formed by large cobble and small boulder substrates resulting from continental glaciation. The frequency of pocket pools is shown in the bed profile. The larger sampled pools were associated with dipping bedrock along the thalweg of the meander outcures.





**Figure B-28.** Longitudinal channel profile graph depicting dominant bed morphology, water surface facet slopes, and bankfull features within Reach 3. The green points represent the bankfull floodplain with a best-fit line, the blue points are the water surface with a best-fit line, and the black points represent the thalweg.

Longitudinal channel profile data are summarized in Table B-44 and B-45. Average water surface slope was 0.0024 ft/ft. Average riffle and pool slopes were 0.0024 ft/ft and 0.0006 ft/ft respectively. Riffle slopes approximated the average water surface slope, and pools were 25% of the average water surface slope (Table B-44).

**Table B-44.** Summary of longitudinal channel profile data (ft).

Valley Slope	Ave. Water Surface Slope	Ave. Riffle Slope	Ave. Pool Slope	Pool to Pool Spacing	Ave. Pool Length (ft)
0.003	0.0024	0.0024	0.0006	2,193	354

As noted above, the primary pools in Reach 3 were associated with dipping and/or fractured bedrock along the channel thalweg. Average pool length was 354 ft with an approximate pool to pool spacing to bankfull width ratio of 11.98 (Table B-45).

**Table B-45.** Summary of longitudinal channel profile dimensionless ratios.

Riffle Slope / Ave. Slope	Pool Slope / Ave. Slope	Pool Length / Bankfull Width	Pool to Pool Spacing / Bankfull Width
1.00	0.25	1.93	11.98

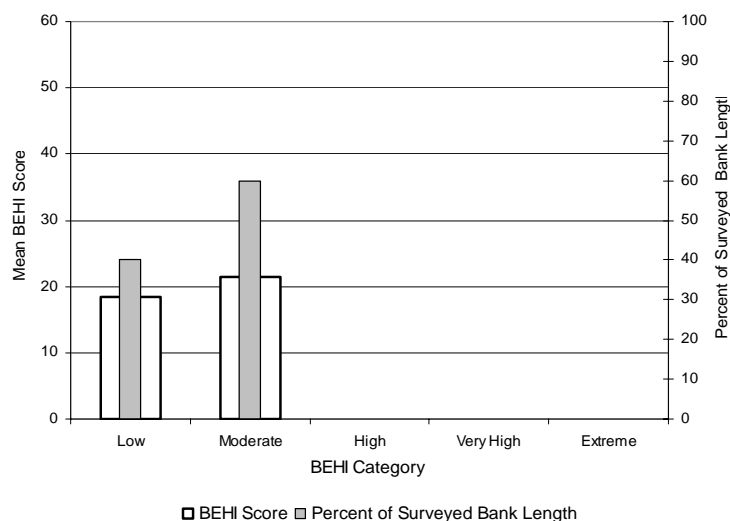
### B.4.5.3 Bank Integrity

The bank integrity analysis included an evaluation of two bank sites with a total surveyed bank length of approximately 1,250 ft within Reach 3. The sites were representative of the varied

conditions within Reach 3, including bedrock formed hillslopes and unconsolidated glacial till and lacustrine mantled slopes (Figure B-29). Figure B-30 summarizes the results. Bank erosion potential for the reach was low to moderate. Slopes mantled with till and finer grained sediments were typically well vegetated offering sufficient bank surface protection from high flows. Numeric BEHI ratings included 18.4 at Site 1 and 21.5 at Site 2.



**Figure B-29.** Bank material composition in Reach 3 ranged from sandy gravel to resistant sedimentary bedrock exposures.



**Figure B-30.** BEHI scores and ratings for representative bank condition sites in Reach 3.

Bank height and root depth ratios averaged 1.0 and .08 for Sites 1 and 2, respectively. Weighted root density included values of 5.8 and 5.0. Bank angle and surface protection was 45 degrees and 80% at both sample banks. Bank material composition was primarily bedrock and gravel with a high fraction of sand and unstable strata.

#### B.4.5.4 Bed Resistance and Channel Hydraulics

Reach 3 was characterized by very coarse gravel substrate, with particles ranging in size from 18 mm (coarse gravel) to a maximum particle size of 512 mm (small boulder). Hydraulic modeling

and incipient motion average results for two riffle cross-section in Reach 3 are presented in Table B-46. Sediment gradation data is summarized in Table B-47.

**Table B-46.** Hydraulic and incipient motion modeling results for bankfull discharge.

Velocity (f/s)	Manning's n-value	Total shear stress (lbs/ft <sup>2</sup> )	Grain Diameter (mm)	Size Class (% finer than)
4.98	0.036	0.56	90-100 <sup>1</sup> 30-40 <sup>2</sup>	D <sub>72</sub> -D <sub>77</sub> D <sub>25</sub> -D <sub>35</sub>

<sup>1</sup> Modified Shields curve (D. Rosgen, 2001)

<sup>2</sup> Shields curve

Comparing the results of the hydraulic modeling to the modified Shields curve and composite sediment gradation data, the channel is capable of initiating motion of a 90 mm to 100 mm particle (D<sub>72</sub>-D<sub>77</sub>) during bankfull discharge. Due to the lack of depositional features, a RSI was not completed in Reach 3.

**Table B-47.** Particle size distributions in Reach 3.

Composite Gradation (mm)					
D <sub>16</sub>	D <sub>35</sub>	D <sub>50</sub>	D <sub>84</sub>	D <sub>95</sub>	D <sub>100</sub>
18	38	54	123	211	512

The standard Shields curve predicted a much small particle size class ranging from 30 mm to 40 mm, or the D<sub>25</sub>-D<sub>35</sub> of the bed material. The standard Shields curve likely under-predicted grain size diameter for the modeled critical shear stress values.

#### B.4.6 BFR – USGS Gaging Station Existing Conditions

The BFR flows through a moderately confined valley in the vicinity of the USGS gaging station near Bonner. The channel has incised into unconsolidated, heterogeneous and erodible glacial outwash terraces that provide a continual source of sediment to the channel in locations where the river interacts with the terrace. Upstream and downstream of the assessed reach, the Highway 200 road fill periodically encroaches on the channel, displacing what minimal floodplain was present prior to construction of the transportation corridor. A majority of the reach was characterized by riffle, run and glide habitat units. Channel-spanning pools were absent in the reach, yet similar to Reach 3 of the BFR near Ovando, coarse lag deposits resulting from continental glaciation formed frequent and irregularly spaced scour pools. Riffle and run bedforms characterized the bed profile and sediment supply derived from the channel bed was considered low. The reach classified as an entrenched F3 channel type and in locations where floodplain was developed, a moderately entrenched B3 channel type predominated.



**Figure B-31.** View of the BFR at the USGS gaging station. The floodplain in the foreground supported dense riparian shrubs. The opposite bank was a glacial outwash terrace standing approximately 4-8 ft from the current bankfull elevation of the river.

#### B.4.6.1 Planform

Results of the planform analysis are summarized in Table B-48. As indicated, valley constraints imposed on the channel limited floodplain development in locations, resulting in relatively entrenched B3 and F3 channel types, and a low sinuous planform. The meander belt width was 500 ft (meander width ratio of 2.6).

**Table B-48.** Existing planform channel dimensions of the BFR at the USGS gage near Bonner. (Average values).

Channel Type	Sinuosity	Bankfull Width (ft)	Entrenchment Ratio	Meander Belt Width (ft)	Meander Length (ft)	Radius of Curvature (ft)
B3	1.15	193	1.34	500	2,400	1,050
F3						

#### B.4.6.2 Channel Cross-Sections

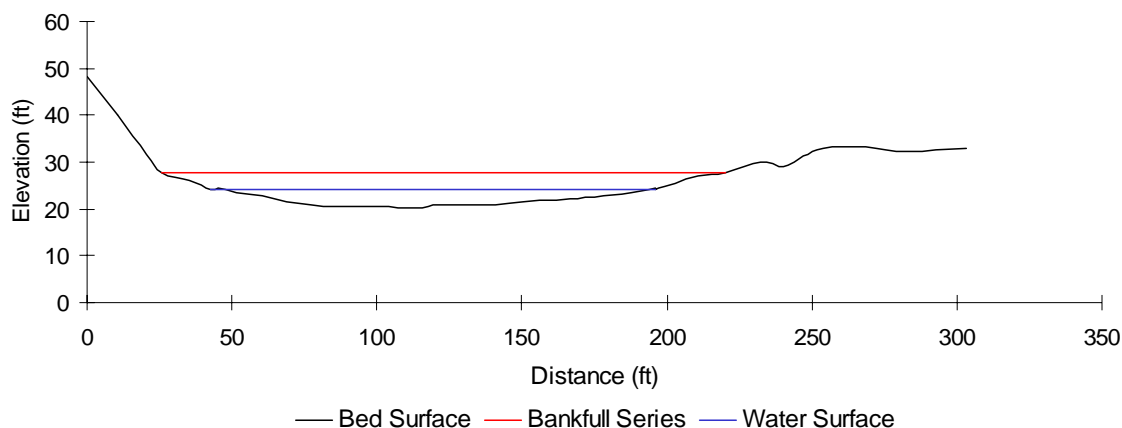
Five cross-sections were surveyed along a 2,800 ft reach of the BFR. Bankfull riffle widths ranged from 182 ft to 204 ft, with corresponding width-to-depth ratios ranging from 36-47, respectively. Maximum riffle depths ranged from 6.2 ft to 7.1 ft with an average value of 6.6 ft. Average bankfull cross-sectional area for riffle habitat units was 815 ft<sup>2</sup>, ranging from 720 ft<sup>2</sup> to 921 ft<sup>2</sup>. Table B-49 summarizes the cross-section data results.

**Table B-49.** Existing cross-section dimensions of the BFR at the USGS gaging station near Bonner. Average value (range).

Habitat Type (n)	Bankfull width (ft)	Average depth (ft)	Width-to-depth ratio	Maximum depth (ft)	Cross-sectional area (ft <sup>2</sup> )
Riffle (2)	193 (182-204)	4.2 (3.9-4.5)	41 (36-47)	6.6 (6.2-7.1)	815 (720-921)
Run (1)	216	5.0	n/a	9.8	1,079
Glide (2)	184 (176-192)	5.0 (4.9-5.2)	n/a	7.4 (7.1-7.6)	924 (856-993)

Glide habitat units characterized the lower section of the reach and were associated with the more entrenched F channel type inclusions. Bankfull widths for glides ranged from 176 ft to 192

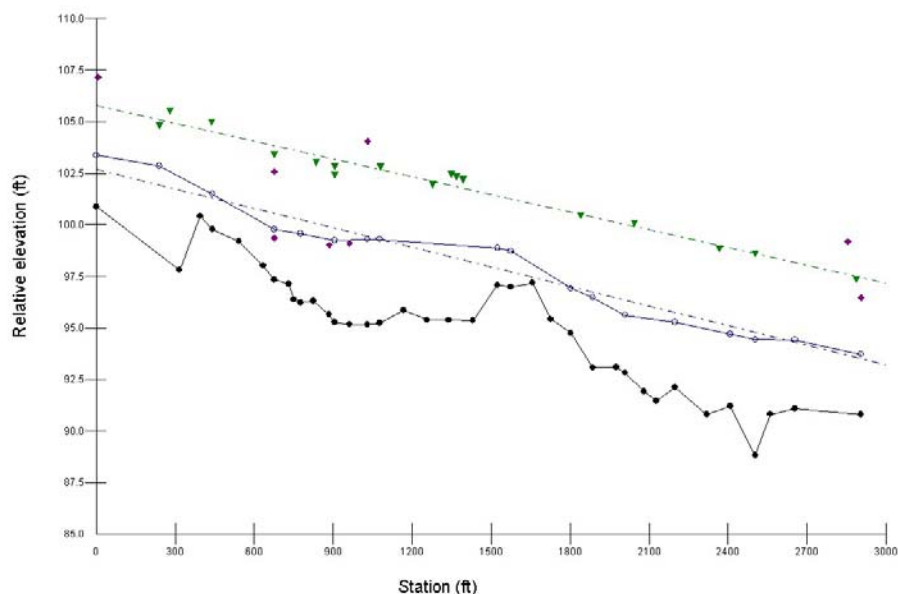
ft, with average depths ranging from 4.9 ft to 5.2 ft. The one sampled run habitat unit was 216 ft in width with an average depth of 5.0 ft and maximum depth of 9.8 ft.



**Figure B-32.** Typical riffle cross-section of the BFR at the USGS gaging station near Bonner.

#### B.4.6.3 Channel Profile

The channel profile is depicted in Figure B-33 and included approximately 2,800 ft of channel. The USGS gaging station was located at Station 8+00 and associated with a stable, glide habitat unit. The low and medium stage control for the cross-section is a broad cobble and small boulder riffle located approximately 700 ft downstream at Station 15+00. As noted, no significant pools were measured during the survey and bedforms were largely characterized by irregularly spaced scour pools and riffle habitat units. The reach was void of large woody debris.



**Figure B-33.** Longitudinal channel profile graph depicting dominant bed morphology, water surface facet slopes, and bankfull features within Reach 1. The green points represent the bankfull floodplain with a best-fit line, the blue points are the water surface with a best-fit line, and the black points represent the thalweg.

Longitudinal channel profile data are summarized in Table B-50 and B-51. Average water surface slope was 0.0032 ft/ft. Average riffle slope was 0.0056 ft/ft or approximately 75% steeper than the average water surface slope. The scour pools associated with lag deposits and boulders were flat, or approximately half of the average water surface slope.

**Table B-50.** Summary of longitudinal channel profile data (ft).

Valley Slope	Ave. Water Surface Slope	Riffle Slope	Pool Slope	Pool to Pool Spacing	Pool Length (ft)
0.004	0.0032	0.0056	n/a	n/a	n/a

Channel spanning pools were absent in the reach, as previously noted. cursory evaluation of pools upstream and downstream of the survey reach indicated maximum pool depths in excess of 15 ft. The pools were formed by large boulders and bedrock intrusions in the channel that caused rapid flow convergence and expansion.

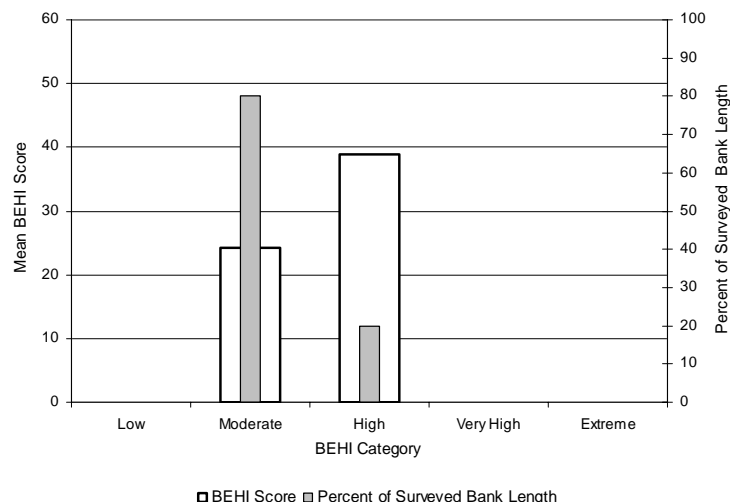
**Table B-51.** Summary of longitudinal channel profile dimensionless ratios.

Riffle Slope / Ave. Slope	Pool Slope / Ave. Slope	Pool Length / Bankfull Width	Pool to Pool Spacing / Bankfull Width
1.75	n/a	n/a	n/a

#### **B.4.6.4 Bank Integrity**

The bank integrity analysis included an evaluation of four bank sites with a total surveyed bank length of approximately 2,900 feet. Surveys extended approximately 200 ft upstream and 2,700 ft downstream of the USGS gaging station. Figure B-34 summarizes the reach results. Bank erosion potential at all sampled sites ranged from moderate to high. Highly erodible sites had unvegetated bank facet slopes with bank heights exceeding 4 ft to 6 ft above bankfull stage. Excessive bank heights commonly precluded development of deep rooting depths, leaving the lower 90% of the bank face susceptible to erosion and dry ravel. Unconsolidated glacial till provided a range of particle sizes to the channel, including fine sands to coarse gravel and cobble.





**Figure B-34.** BEHI scores and ratings for representative bank condition sites of the BFR at the USGS gage station near Bonner.

Bank height ratios were less than 2.0, ranging from 1.0 to 1.9. Root depth ratios ranged from 0.0 to 0.1. Weighted root density included values of 0.0, 1.3, 2.2, and 3.6. Bank angles ranged from 20 to 60 degrees and surface protection from 45 to 80 percent. Bank material composition was primarily cobble with a high fraction of sand and unstable strata. Bank composition at Site 4 included boulders and unstable strata. Numeric BEHI ratings included 27.2 at Site 1, 23.8 at Site 2, 21.9 at Site 3, and 38.9 at Site 4. Eighty percent (80%) of the surveyed bank rated moderate in terms of bank erosion potential, while the remaining 20% rated high.

#### B.4.6.5 Bed Resistance and Channel Hydraulics

The BFR at the USGS gaging station was characterized by very coarse gravel substrate, with particles ranging in size from 18 mm (small cobble) to a maximum particle size of 512 mm (small boulder). Hydraulic modeling and incipient motion average results for two typical riffle-run cross-sections are presented in Table B-52.

Velocity (f/s)	Manning's n	Total shear stress (lbs/ft <sup>2</sup> )	Grain Diameter (mm)	Size Class (% finer than)
6.6	0.035	0.90	115-125 <sup>1</sup> 60-70 <sup>2</sup>	D <sub>50</sub> -D <sub>55</sub> D <sub>30</sub> -D <sub>35</sub>

<sup>1</sup> Modified Shields curve (D. Rosgen, 2001)

<sup>2</sup> Shields curve

Comparing the results of the hydraulic modeling to the modified Shields curve and composite sediment gradation data (Table B-53), the channel is capable of initiating motion of a 115 mm to 125 mm particle (D<sub>50</sub>-D<sub>55</sub>) during bankfull discharge. Due to the lack of depositional features, an RSI was not completed in Reach 3.

**Table B-53.** Particle size distributions in Reach 3.

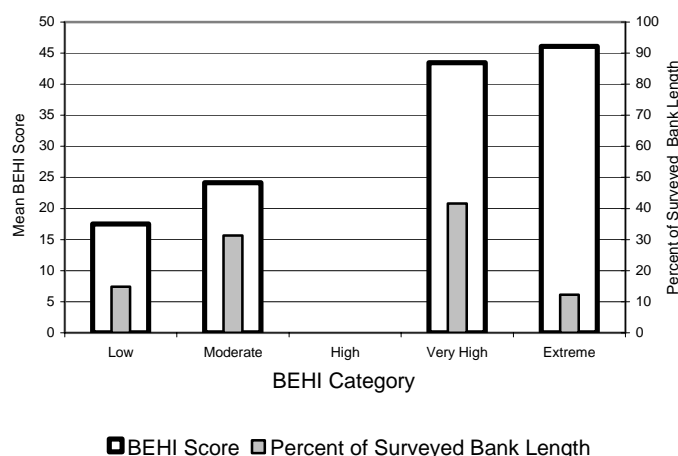
Composite Gradation (mm)					
D <sub>16</sub>	D <sub>35</sub>	D <sub>50</sub>	D <sub>84</sub>	D <sub>95</sub>	D <sub>100</sub>
24	68	100	200	294	512

The standard Shields curve predicted a much small particle size class ranging from 60 mm to 70 mm, or the D<sub>30</sub>-D<sub>35</sub> of the bed material. The standard Shields curve likely under-predicted grain size diameter for the modeled critical shear stress values.

## B.4.7 Discussion

### B.4.7.1 Blackfoot River near Ovando

The reach assessments completed on the Blackfoot River near Ovando quantitatively described the geomorphic character of a system transitioning from an unconfined, alluvial valley to a confined, structurally controlled type. As the floodprone area and meander belt width were constricted in a down valley direction, adjustments in channel morphological characteristics were observed, including, width, depth, pool to pool spacing, and meander geometry relationships. In the three measured reaches, the channel geometry was balanced with the prevailing streamflow and sediment regime, with no net aggradation or degradation or significant reduction in sediment transport competency, despite relatively high rates of potential sediment loading compared to channels of similar type and morphology on the Clark Fork River (CFR3-B and CFR1 at Bandmann Flats). Overall, bank erosion potential in the Ovando assessment area varied from low to extreme. The distribution of conditions included low (15%), moderate (31%), very high (42%) and extreme (12%) (Figure B-35). In general, bank erosion potential rated greatest in Reach 1 relative to Reaches 2 and 3.



**Figure B-35.** Composite BEHI scores and ratings for the Blackfoot River near Ovando, Reaches 1, 2 and 3.

The results and observations from the Blackfoot River near Ovando reach assessment indicate that natural channels can transition from unconfined, alluvial valley types to confined types and maintain a stable, single-threaded channel plan form. Applied in conjunction with other

analytical and empirical analyses, the data sets developed from this assessment can be converted to dimensionless form and used to refine channel and floodplain design dimensions for the Clark Fork and Blackfoot rivers within CFR3, CFR2, CFR1 and BFR1.

#### **B.4.7.2 Blackfoot River near Bonner**

The Blackfoot River near Bonner at the USGS gaging station represented a stable, functioning channel developed within a narrow, confined valley type. The reach classified as an entrenched F3 channel type and in locations where floodplain was developed, a moderately entrenched B3 channel type predominated. The channel is incised into unconsolidated, heterogeneous and erodible glacial outwash terraces that provide a continual source of sediment to the channel in locations where the river interacts with the terrace. Eighty percent (80%) of the surveyed bank rated moderate in terms of bank erosion potential, while the remaining 20% rated high. Sediment supply derived from the channel bed was considered low.

This reach is similar in terms of valley form and channel type potential to the lower reaches of the Blackfoot River upstream of the confluence with the Clark Fork River (BFR1). The dimensionless ratios generated from the reach assessment can be used to supplement companion analyses being conducted to develop channel design dimensions for BFR1.

### **B.5 REFERENCE REACH DATA SUMMARY**

This section compiles and summarizes reference reach field data collected on the CFR and BFR. The data is presented in table format. Six reaches were identified as potential reference reaches within the project area. The reaches represented stable channel conditions and were stratified by valley and stream type according to Rosgen (1996). Specific data on stream channel dimension, pattern, profile and channel materials were measured and summarized in Sections B.3 (CFR) and B.4 (BFR) of this report. The data were analyzed and converted into dimensionless ratios by channel type. The dimensionless ratios were extrapolated to river reaches within the Milltown restoration project area displaying similar valley type and potential stream channel conditions. The data sets supplemented companions hydraulic and geomorphic analyses used in developing the channel and floodplain design dimensions within CFR3, CFR2, CFR1 and BFR1.

Table B-54 lists the reference reaches and associated Rosgen channel type from which the dimensionless ratios were developed.

**Table B-54.** List of reference reaches and associated stream types (Rosgen, 1996).

River Reach	Reach I.D.	Stream Type
Clark Fork River Reach 3 (CFR 3-B)	CFR3-B C Reach	C
Clark Fork River Reach 1	CFR1B Reach / Bandmann F Reach	B/F
Blackfoot River near Ovando Reach 1	Ovando C Reach	C
Blackfoot River near Ovando Reach 2	Ovando B Reach	B
Blackfoot River near Ovando Reach 3	Ovando F Reach	F
Blackfoot River at USGS Gaging Station	Bonner B Reach	B

**Table B-55.** Dimensionless coefficients for the reference reach pool dimensions stratified by stream type.

Reach	Pool Area/ Riffle Area			Pool Max Depth/ Riffle Mean Depth			Pool Width/ Riffle Width		
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR 3-B C Reach	1.13	0.86	1.41	2.35	2.29	2.38	1.00	0.93	1.16
Ovando C Reach	0.96	0.79	1.08	2.42	1.94	3.33	0.83	0.72	0.9
Ovando B Reach	1.10			2.60			0.90		
Bonner B Reach									
Ovando F Reach	1.29	1.26	1.33	2.26	2.12	2.41			
Bandmann F Reach	1.50	0.90	2.00	5.20	5.00	5.40	0.72	0.63	0.83

**Table B-56.** Dimensionless coefficients for reference reach run and riffle dimensions stratified by stream type.

Reach	Run Max Depth/ Riffle Mean Depth			Riffle Max Depth/ Riffle Mean Depth			Run Width/ Riffle Width		
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR 3 C Reach	2.42	2.4	2.45	2.42	2.4	2.45	2.42	2.4	2.45
Ovando C Reach	1.75	1.34	2.29	1.75	1.34	2.29	1.75	1.34	2.29
Ovando B Reach	1.76	1.42	2.10	1.76	1.42	2.10	1.76	1.42	2.10
Bonner B Reach									
Ovando F Reach	1.65			1.65			1.65		
Bandmann F Reach	1.90	1.80	1.99	1.90	1.80	1.99	1.90	1.80	1.99

**Table B-57.** Dimensionless coefficients for the reference reach channel habitat unit slopes stratified by stream type.

Reach	Pool Slope/ Average Slope			Riffle Slope/ Average Slope			Run Slope/ Average Slope			Pool to Pool Spacing/ Riffle Width		
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR 3 C Reach	0.20	0.12	0.24	2.34	1.19	3.77	0.50	0.25	0.76	3.76		
Ovando C Reach	0.35	0.00	0.85	1.53	0.41	5.22	0.80	0.00	2.97	5.26	1.29	19.90
Ovando B Reach	0.33			2.15	1.14	4.42	0.86	0.58	1.02	10.80		
Bonner B Reach				1.70	0.51	2.42	0.70	0.52	0.91			
Ovando F Reach	0.23	0.03	0.44	0.98	0.46	1.38	0.71	0.50	0.98	11.96		
Bandmann F Reach	0.00	0.00	0.05	1.36	1.05	1.82	3.37	0.21	5.92			

**Table B-58.** Dimensionless coefficients for the reference reach planform geometry stratified by stream type.

Reach	Meander Length/ Riffle Width			Radius of Curvature/ Riffle Width			Beltwidth / Riffle Width		
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR 3 C Reach	9.60	8.25	10.93	2.40	2.22	2.56	3.80	3.41	4.10
Ovando C Reach	10.20	5.38	15.40	2.57	0.88*	4.08	4.70	2.91	7.64
Ovando B Reach	9.20	8.47	9.83	10.10	9.46	10.82	2.00	1.39	2.70
Bonner B Reach	12.50			5.50			2.60		
Ovando F Reach	11.20	8.45	13.79	3.70	2.55	4.77	2.86	2.81	2.89
Bandmann F Reach	19.20			8.37			6.30		

\*: Value was measured at a bedrock control segment and is not representative of an alluvial meander.

The dimensionless coefficients were converted to channel dimensions for each of the project reaches by multiplying the dimensionless coefficient by the reach-specific bankfull channel value for the specific variable (Table 59 through Table 63).

**Table B-59.** Calculated pool dimensions for the restoration project reaches. Dimensionless coefficients provided in Table B-55 were multiplied by design riffle dimensions to derive pool dimensions.

Reach (Source Coeffs)	Riffle Area (ft <sup>2</sup> )	Riffle Depth (ft)	Riffle Width (ft)	Pool Area (ft <sup>2</sup> )			Pool Max Depth (ft)			Pool Width (ft)		
				Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3/CFR2 C (CFR3)	550	3.7	148	622	473	776	8.7	8.5	8.8	148	138	172
CFR3/CFR2 C (Ovando C)	550	3.7	148	528	435	594	9.0	7.2	12.3	123	107	133
CFR2 B (Ovando B)	530	3.6	146	583			9.4			131		
CFR2 B (Bonner B)												
BFR1 (Ovando F)	960	4.9	196	1238	1210	1277	11.1	10.4	11.8			
BFR1 (Bandmann F)	960	4.9	196	1440	864	1920	25.5	24.5	26.5	141	123	163
CFR1 (Ovando F)	1480	6.1	243	1909	1865	1968	13.8	12.9	14.7			
CFR1 (Bandmann F)	1480	6.1	243	2220	1332	2960	31.7	30.5	32.9	175	153	202

**Table B-60.** Calculated run and riffle dimensions for the restoration project reaches. Dimensionless coefficients provided in B-56 were multiplied by design riffle dimensions to derive the run and riffle max depth dimensions.

Reach (Source Coeffs)	Riffle Area (ft <sup>2</sup> )	Riffle Depth (ft)	Riffle Width (ft)	Run Max Depth (ft <sup>2</sup> )			Run Width (ft)			Riffle Max Depth (ft)		
				Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3/CFR2 C (CFR3)	550	3.7	148	9.0	8.9	9.1	129	121	135	5.6	4.5	7.2
CFR3/CFR2 C (Ovando C)	550	3.7	148	6.5	5.0	8.5	135	117	152	5.2	4.5	5.7
CFR2 B (Ovando B)	530	3.6	146	6.3	5.1	7.6	117	117	123	5.1	4.5	5.9
CFR2 B (Bonner B)												
BFR1 (Ovando F)	960	4.9	196	8.1			186			7.8	6.4	9.2
BFR1 (Bandmann F)	960	4.9	196	9.3	8.8	9.8	153	151	155	7.0	6.6	7.3
CFR1 (Ovando F)	1480	6.1	243	10.1			231			9.7	8.0	11.5
CFR1 (Bandmann F)	1480	6.1	243	11.6	11.0	12.1	190	187	192	8.7	8.2	9.0

**Table B-61.** Calculated planform dimensions for the restoration project reaches. Dimensionless coefficients provided in Table B-58 were multiplied by design riffle dimensions to derive the planform dimensions.

Reach (Source Coeffs)	Bankfull Width (ft)	Meander Length (ft)			Radius of Curvature (ft)			Beltwidth (ft)		
		Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3/CFR2 C Reach (CFR3)	148	1,421	1,221	1,618	355	329	379	562	505	607
CFR3/CFR2 C Reach (Ovando C)	148	1,510	796	2,279	380	130	604	696	431	1,131
CFR2 B (Ovando B)	146	1,343	1,237	1,435	1,475	1,381	1,580	292	203	394
CFR2 B (Bonner B)	146	1,825			803			380		
BFR1 (Ovando F)	196	2,195	1,656	2,703	725	500	935	561	551	566
BFR1 (Bandmann F)	196	3,763			1,641			1,235		
CFR1 (Ovando F)	243	2,722	2,053	3,351	899	620	1,159	695	683	702
CFR1 (Bandmann F)	243	4,666			2,034			1,531		



**Table B-62.** Calculated habitat feature slopes for the restoration project reaches. Dimensionless coefficients provided in Table B-57 were multiplied by average slope to derive the habitat feature slopes.

Reach (Source Coeffs)	Ave Slope	Pool Slope			Riffle Slope			Run Slope		
		Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3/CFR2 C (CFR3)	0.0027	0.0005	0.0003	0.0006	0.0063	0.0032	0.0102	0.0014	0.0007	0.0021
CFR3/CFR2 C (Ovando C)	0.0027	0.0009	0.0000	0.0023	0.0041	0.0011	0.0141	0.0022	0.0000	0.0080
CFR2 B (Ovando B)	0.0036	0.0012	0.0000	0.0000	0.0077	0.0041	0.0159	0.0031	0.0021	0.0037
CFR2 B (Bonner B)	0.0036				0.0061	0.0018	0.0087	0.0025	0.0019	0.0033
BFR1 (Ovando F)	0.0030	0.0007	0.0001	0.0013	0.0029	0.0014	0.0041	0.0021	0.0015	0.0029
BFR1 (Bandmann F)	0.0030	0.0000	0.0000	0.0002	0.0041	0.0032	0.0055	0.0101	0.0006	0.0178
CFR1 (Ovando F)	0.0031	0.0007	0.0001	0.0014	0.0030	0.0014	0.0043	0.0022	0.0016	0.0030
CFR1 (Bandmann F)	0.0031	0.0000	0.0000	0.0002	0.0042	0.0033	0.0056	0.0104	0.0007	0.0184

**Table B-63.** Calculated pool to pool spacing for the project reaches. Spacing is the product of the riffle width and the dimensionless coefficients included in Table B-57.

Reach (Source Coeffs)	Bankfull Width (ft)	Pool to Pool Spacing (ft)		
		Ave	Min	Max
CFR3/CFR2 C (CFR3)	148	556		
CFR3/CFR2 C (Ovando C)	148	778	191	2945
CFR2 B (Ovando B)	146	1577		
CFR2 B (Bonner B)	146			
BFR1 (Ovando F)	196	2344		
BFR1 (Bandmann F)	196			
CFR1 (Ovando F)	243	2906		
CFR1 (Bandmann F)	243			